An Examination of the Growth, Behaviour, and Biochemical Responses of Juvenile Coho Salmon (*Oncorhynchus kisutch*) at the Capilano Salmon Hatchery, North Vancouver, BC, in Relation to Changes in Water Quality and Food Between November 2001 and May 2002

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AN EXAMINATION OF THE GROWTH, BEHAVIOUR, AND BIOCHEMICAL RESPONSES OF JUVENILE COHO SALMON (*Onchorhyncus Kisutch)* AT THE CAPILANO SALMON HATCHERY, NORTH VANCOUVER, BC, IN RELATION TO CHANGES IN WATER QUALITY AND FOOD BETWEEN NOVEMBER 2001 AND MAY 2002

by

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PREFACE

It was necessary for the Greater Vancouver Water District (GVWD) to reduce the volume of water in the Capilano Reservoir behind the Cleveland Dam, North Vancouver, BC in order to carry out maintenance work over the winter of 2001/2002. The Capilano Salmon Hatchery uses water that is drawn from this reservoir for fish husbandry and, accordingly, it is necessary to maintain its' high quality. Concern was expressed over the potential for the quality of the water to be reduced by the introduction of fine sediments during the dam maintenance period. Such materials could originate from the exposed reservoir's shore during rainfall. In addition, sediments entering the reduced water volume of the reservoir would not receive the same dispersion as they would have done had they had entered a full reservoir. Thus, the potential existed for turbid waters containing elevated levels of suspended sediments to enter the Capilano Salmon Hatchery.

In the late winter and spring of 1999, staff at the Capilano Salmon Hatchery recorded a reduction of the growth of their fish when there had been elevated levels of suspended sediment and turbidity in the hatchery waters. Such responses were consistent with the findings from studies that have assessed the effects of suspended sediment and turbidity on the ability of fish to feed and grow. However, and unexpectedly, poor conversion of food by the fish was observed for a number of weeks after the cessation of turbid conditions, but in general the fish grew well during the period of elevated suspended sediment and turbidity. At the time of release from the hatchery some fish were smaller than that predicted and expected. Because of these findings hatchery staff expressed their concern over the potential for turbid water to yet again enter the hatchery in winter 2001/2002. They were appropriately concerned about the potential effect on the feeding and growth of fish to the extent that these fish would also be smaller at the time of release and, in turn, this could affect subsequent survival to adulthood.

As a precautionary measure, and in anticipation of elevated levels of suspended sediment and turbidity in the hatchery waters during winter 2001/2002, the fish were given additional food in the late summer and early fall. It was expected that this increased food would result in enhanced growth of the fish prior to winter thereby offsetting any potential reduction in growth that may occur due to sediment input thereafter. Thus, it was expected that this precautionary measure would result in an appropriate size of fish at the time of release in spring.

The GVWD was similarly concerned over the maintenance of water quality and the health of biological resources in the Capilano River watershed. They responded by funding a number of studies and habitat compensatory activities during the maintenance work on the Cleveland Dam, a requirement of the GVWD, and specified in an Authorization (#96-HPAC-PA2-000-000491) under the Fisheries Act for the Cleveland Dam, East Abutment Seepage Control Project. This report documents one research component of these studies.

The deductions and opinions presented herein are those of the authors.

TABLE OF CONTENTS

PREFACE III

ABSTRACT VII

RÉSUMÉ VIII

LIST OF TABLES IX

LIST OF FIGURES XII

INTRODUCTION 1

MATERIALS AND METHODS 4

Fish History 4
Test Apparatus 4
Water Supply 6
Initiation of Experiments 6
Troughs 6
Tanks 6
Water Quality Monitoring 7
Suspended Sediment 8
pH, Flow Rate and Total Gas Pressure 8
Particle Size Analysis 8
Invertebrates 9
Light Intensity 9
Trough and Tank Maintenance 9
Feeding of Fish 10
Experimental Sampling Protocol 11
Growth 11
Troughs 12
Tanks 12
Biochemical Analysis 12
Sampling 12
Chemicals 13
RNA:DNA Ratio Determination 13
Triglyceride Concentration Determination 14
Protein Concentration Determination 14
Assay Performance Determination 14
Cover Response Trials 15
Apparatus 15
Pre-trial Procedures 15
Trial Procedures 16

DATA ANALYSIS AND RESULTS 17

Water Quality Parameters 17

Troughs 17
Temperature 17
Turbidity 18
Dissolved Oxygen: 18
Tanks 18
Temperature –Turbidity Relationship 19
Supply Line Turbidity 20
Suspended Sediment 20
Particle Size 20
Invertebrates 20
Light Intensity 21
Basement Chamber 5 Water Quality 21
Fish Survival 21
Length and Mass Determinations 21
Troughs 21
Statistical Model 23
Tanks 23
Statistical Model 24
Bch 5 25
Biochemical Analysis 25
Triglyceride Concentration: 26
Protein Concentration: 26
DNA Concentration: 27
RNA Concentration: 27
RNA:DNA Ratio: 28
Cover Response Trials 28
Digital Video Analysis 28
Water Quality Parameters 29
Results 29
Statistical Model 29
Time 29
Speed 30
Orientation 31
Direction 32
Severity of Ill Effects 33

DISCUSSION 34

General Considerations 34
Water Quality 34
Suspended Sediment and Turbidity 35
Predicted Severity of Ill Effect (SIE) scores 36
Responses of Fish 38
Survival 38
Growth and Condition 39
Deductions from Results 43
Biochemistry 44
Triglyceride and Protein 46

DNA and RNA 46
Deductions from Results 47
Behaviour 48
Cover Response 49
Deductions from Results 51

CONCLUDING COMMENTS 51

ACKNOWLEDGEMENTS 53

REFERENCES 54

APPENDIX I – 1999 HISTORICAL DATA 115

Summary of Data and Findings 115

APPENDIX II - EXPERIMENTAL CONSIDERATIONS AND DESIGN 123

ABSTRACT

Birtwell, I.K., J.S. Korstrom, P.M.F. Walton, C.J. Whitfield, and D.M. Janz. 2003. An examination of the growth, behaviour, and biochemical responses of juvenile coho salmon (*Oncorhyncus kisutch*) at the Capilano Salmon Hatchery, North Vancouver, BC, in relation to changes in water quality and food between November 2001 and May 2002. Can. Tech. Rep. Fish. Aquat. Sci. 2499: 127 p.

Maintenance activities on the Cleveland Dam in North Vancouver, BC, during winter 2001/2002, and the reduced volume of the Capilano Reservoir, were expected to result in elevated concentrations of suspended sediment in the reservoir waters. These waters supply the Capilano Salmon Hatchery and accordingly there was concern over potential effects on fish. This study addressed that concern by examining the growth, survival, food ration, biochemistry and behaviour of juvenile coho salmon at the hatchery over a 6.5-month period between November 2001 and May 2002. It was predicted (Severity of Ill Effects model; Newcombe and Jensen, 1996) that there could be progressive ill effects on the salmon related to the sediment concentrations they encountered and to the duration of exposure to them. However, the recorded suspended sediment levels the fish experienced (maximum and mean sediment concentrations among the experimental holding tanks were 18.5, and 2.7 - 3.0 $mg \cdot L^{-1}$, respectively) were below those used to construct the predictive model. To our knowledge no appropriate data revealing adverse effects at such low mean suspended sediment levels exist.

There was no demonstrable effect of changes in suspended sediment and turbidity that affected the well being and growth of the fish that were sampled at 21-d intervals. Survival of the 4,200 experimental fish was 99.5%. Their fright response to seek cover, which can be compromised through exposure to stressful circumstances, was rapid (<3s) throughout the testing period. Changes in the growth, condition and biochemistry (triglycerides, protein, RNA/DNA ratio) of the coho salmon were most attributable to food rations and to water temperature.

It was deduced that changes in water quality during maintenance activities on the Cleveland Dam did not adversely affect the experimental populations of coho salmon held at the Capilano Salmon Hatchery.

RÉSUMÉ

Birtwell, I.K., J.S. Korstrom, P.M.F. Walton, C.J. Whitfield, and D.M. Janz. 2003. An examination of the growth, behaviour, and biochemical responses of juvenile coho salmon (*Oncorhyncus kisutch*) at the Capilano Salmon Hatchery, North Vancouver, BC, in relation to changes in water quality and food between November 2001 and May 2002. Can. Tech. Rep. Fish. Aquat. Sci. 2499: 127 p.

On avait prévu que les travaux d'entretien du barrage Cleveland, à North Vancouver (Colombie-Britannique), à l'hiver 2001-2002, et la réduction du volume du réservoir de Capilano entraîneraient une augmentation des concentrations de sédiments en suspension dans les eaux du réservoir. Ces eaux alimentent l'écloserie de saumons de Capilano; c'est pourquoi l'on s'inquiétait des effets potentiels sur les poissons. Dans le cadre de l'étude, nous avons examiné la croissance, la survie, la ration alimentaire, la biochimie et le comportement des cohos juvéniles de l'écloserie pendant 6 mois et demi, de novembre 2001 à mai 2002. Dans leur échelle de gravité des effets nocifs, Newcombe et Jensen (1996) avaient prévu qu'il était possible que les concentrations de sédiments et la durée d'exposition à ces sédiments aient des effets nocifs progressifs sur les saumons. Toutefois, les concentrations de sédiments en suspension observées auxquelles ont été soumis les poissons (la teneur maximale dans les réservoirs-viviers expérimentaux était de 18,5 $mg \cdot L^{-1}$, et la teneur médiane, de 2,7-3,0 $mg \cdot L^{-1}$) étaient inférieures à celles utilisées dans la construction du modèle de prédiction. Selon nous, aucune donnée fiable ne révèle des effets négatifs quand les concentrations moyennes des sédiments en suspension sont aussi faibles.

Nous n'avons noté aucun effet évident des changements dans les sédiments en suspension et la turbidité qui affecterait le bien-être et la croissance des poissons échantillonnés à des intervalles de 21 jours. Le taux de survie des 4 200 poissons expérimentaux était de 99,5 %. La réaction de recherche d'abri des poissons effrayés, quand ils ont peur, qui peut être compromise par l'exposition à des conditions stressantes, était rapide (< 3 secondes) pendant toute la période d'essai. Les changements dans la croissance, l'état et la biochimie (triglycérides, protéines, ratio ARN/ADN) des cohos étaient pour la plupart attribuables à la ration alimentaire et à la température de l'eau.

Nous avons donc déduit que les changements dans la qualité de l'eau pendant les travaux d'entretien du barrage Cleveland n'ont pas affecté les populations expérimentales de saumons cohos gardées dans l'écloserie de saumons de Capilano.

LIST OF TABLES

Table 1. Mean weekly temperature and dissolved oxygen measurements in waters of Bch 5A at the Capilano Salmon Hatchery between July 2001 and June 2002. 62

Table 2. Mean weekly temperature and dissolved oxygen measurements in waters of Bch 5B at the Capilano Salmon Hatchery between July 2001 and June 2002. 64

Table 3. Sampling schedule for experiments conducted at Capilano Salmon Hatchery between November 21, 2001 and May 30, 2002..... 66

Table 4. Mean and standard deviation of daily water quality determinations from November 21, 2001 to May 30, 2002 in each experimental trough at the Capilano Salmon Hatchery. 67

Table 5. Mean and standard deviation of water quality parameters per 21-d sampling period, measured daily in all experimental troughs at the Capilano Salmon Hatchery, 2001-2002. 68

Table 6. Monthly mean and standard deviation of temperature data logged hourly in each experimental trough at the Capilano Salmon Hatchery, 2001-2002..... 69

Table 7. Mean and standard deviation of water quality parameters determined in each experimental tank between November 21, 2001 and May 29, 2002 at the Capilano Salmon Hatchery ..70

Table 8. Mean and standard deviation of water quality parameters determined in all experimental tanks at the Capilano Salmon Hatchery by 21-d sampling period, 2001-2002. 71

Table 9. Monthly mean and standard deviation of temperature data logged hourly in each experimental tank at the Capilano Salmon Hatchery, 2001-2002. 72

Table 10. Monthly mean, minimum, maximum and standard deviation of turbidity logged hourly in water supplied to Basement Chamber 3 at the Capilano Salmon Hatchery, 2001-2002. ...73

Table 11. Determinations of the turbidity and suspended sediment in waters from the Capilano River as well as in the tanks and troughs at the Capilano Salmon Hatchery, 2001-2002. .74

Table 12. Particle size analysis of suspended sediment from samples of water collected from the Basement Chamber 3 supply line, once during a period of increased turbidity and again during a period of low turbidity, 2002.....75

Table 13. Macroinvertebrate (>200µm) counts in 57,600 L of water collected during the winter and spring from the Basement Chamber 3 supply line at the Capilano Salmon Hatchery, 2002. 76

Table 14. Light Intensity measured in experimental tanks at the Capilano Salmon Hatchery, Nov 16, 2001. 77

Table 15. Light intensity measured in experimental troughs at the Capilano Salmon Hatchery, 2002. 78

Table 16. Length (mm), mass (g) and Body Condition Index of juvenile coho sampled every 21-d, in experimental troughs at the Capilano Salmon Hatchery, n=50 per trough, 2001-2002 79

Table 17. Length (mm) of juvenile coho salmon fed a normal regime in experimental tanks, determined every 21-d, n=20 per tank, at the Capilano Salmon Hatchery, 2001-2002.....80

Table 18. Mass (g) of juvenile coho salmon fed a normal regime in experimental tanks, determined every 21-d, n=20 per tank, at the Capilano Salmon Hatchery, 2001-2002.....81

Table 19. Body Condition Index of juvenile coho salmon fed a normal regime in experimental tanks, determined every 21-d, n=20 per tank, at the Capilano Salmon Hatchery, 2001-2002 82

Table 20. Mean mass of hatchery raised juvenile coho salmon at the Capilano Salmon Hatchery, 2001-2002. 83

Table 21. Length, mass, RNA, DNA, protein and triglyceride content of juvenile coho salmon fed a normal or augmented regime in troughs at the Capilano Salmon Hatchery, 2001-2002....84

Table 22. Water quality parameters determined at the time of the cover response trials at the Capilano Salmon Hatchery, 2002. 85

Table 23. Light intensity determined prior to each trial in the cover response tank at the Capilano Salmon Hatchery, 2002.....86

Table 24. Mean length, mass, time, distance and speed ($cm \cdot s^{-1}$, $bodylengths \cdot s^{-1}$) of juvenile coho salmon in response to cover 75 cm away, in trials conducted at the Capilano Salmon Hatchery (n=10; pooled: n=20).....87

Table 25. Calculations of Severity of Ill Effect scores following exposure of juvenile coho salmon to suspended sediment at the Capilano Salmon Hatchery, 2001-2002.....88

Table 26. Severity of Ill Effect scores following exposure of juvenile coho salmon to suspended sediment at Capilano Salmon Hatchery, 2001-2002.....90

Table 27. Total monthly precipitation at the North Vancouver Cleveland Weather Station, November 2001- June 2002, and 30 y averages, Environment Canada. 93

Table 28. Summary of selected data on water quality, fish and food ration in experimental troughs at the Capilano Salmon Hatchery from November 22, 2001 to May 30, 2002. 94

Table 29. Summary of selected data on water quality, fish and food ration in experimental tanks at the Capilano Salmon Hatchery from November 21, 2001 to May 29, 2002 95

LIST OF FIGURES

Figure 1. Birds eye view of experimental chamber (Bch 3) at the Capilano Salmon Hatchery, 2001-2002. 99

Figure 2. Schematic diagram of the cover response trial apparatus used at the Capilano Salmon Hatchery from January to May 2002. 100

Figure 3. Daily determinations of turbidity (NTU) and temperature (° C) in experimental troughs between November 21, - May 30, 2002 at the Capilano Salmon Hatchery..... 101

Figure 4. Daily determinations of turbidity (NTU) and temperature (° C) in experimental tanks between November 21, 2001 and May 30, 2002 at the Capilano Salmon Hatchery. 102

Figure 5. Turbidity (NTU) determined hourly in the water supply line to the experimental troughs and tanks between November 2001 and June 2002 at the Capilano Salmon Hatchery.... 103

Figure 6. Determinations of suspended sediment in water samples from experimental troughs and tanks between November 20, 2001 to June 4, 2002 at the Capilano Salmon Hatchery. .. 104

Figure 7. Relationship between turbidity (NTU) and suspended sediment of experimental waters (troughs and tanks) at the Capilano Salmon Hatchery, November 2001 to June 2002. ... 105

Figure 8. Mean length of juvenile coho salmon reared in experimental troughs, fed augmented (#1 and #2) and normal (#3 and #4) regimes at the Capilano Salmon Hatchery, 2001-2002. 106

Figure 9. Mean mass of juvenile coho salmon reared in experimental troughs, fed augmented (#1 and #2) and normal (#3 and #4) regimes at the Capilano Salmon Hatchery, 2001-2002. 107

Figure 10. Mean Body Condition Index (BCI) of juvenile coho salmon reared in experimental troughs, fed augmented (#1 and #2) and normal (#3 and #4) regime at the Capilano Salmon Hatchery, 2001-2002..... 108

Figure 11. Percentage change in mass of juvenile coho salmon reared in experimental troughs, fed augmented (#1 and #2) and normal (#3 and #4) regimes relative to initial determinations at the Capilano Salmon Hatchery, 2001-2002. 109

Figure 12. Mean length (mm) of juvenile coho salmon held in experimental tanks (n=20 per tank) from November 21 2001 to May 29, 2002 at the Capilano Salmon Hatchery; all fish in tanks received the same feeding regime. 110

Figure 13. Mean mass (g) of juvenile salmon held in experimental tanks (n=20 per tank) from November 21 2001 to May 29, 2002 at the Capilano Salmon Hatchery; all fish in tanks received the same feeding regime. 111

Figure 14. Mean Body Condition Index of juvenile salmon held in experimental tanks (n=20 per tank) from November 21 2001 to May 29 2002 at the Capilano Salmon Hatchery; all fish in tanks received the same feeding regime. 112

Figure 15. Percentage change in mean mass of juvenile coho salmon (n=20 per tank) relative to initial determinations held in experimental tanks from November 21, 2001 to May 29, 2002 at the Capilano Salmon Hatchery, all fish fed on the same regime. 113

INTRODUCTION

Maintenance activities were undertaken on the Cleveland Dam, North Vancouver, BC, during the fall and winter 2001/2002. These "East Abutment Seepage Control" activities were carried out under the auspices of the Greater Vancouver Water District (GVWD) and necessitated a significant reduction in the dams impounded waters that comprises the Capilano Reservoir. Draw down of the reservoir commenced in early September 2001. It was at its lowest elevation from October 6, 2001 to April 2, 2002. Refilling occurred from this latter date and was completed June 25, 2002. Concern was expressed over the potential for negative impacts on the quality of the reservoir waters and associated implications to aquatic resources (Klohn-Crippen Consultants Ltd., 2000). In particular, there was concern about increases in the turbidity of, and suspended material in, the waters due to soil erosion during the period of the reservoir draw down and construction activities. Changes that would be in addition to "landslide or extreme events", that could not be predicted beforehand, but which had occurred previously during reservoir draw down and also while the reservoir was at "full pool level" (Klohn-Crippen Consultants Ltd., 2000). Elevation in the level of suspended sediment and turbidity in the reservoir waters could impact the fish held at the Capilano Salmon Hatchery, which draws water from the reservoir, and also affect organisms downstream, in the Capilano River.

There is a large amount of information in the world-wide scientific literature that documents the effects of exposing aquatic organisms to sediment, however, much of the information is related to short-term studies (days) using relatively high levels (thousands to tens of thousands $mg \cdot L^{-1}$) of suspended sediment (refer to European Inland Fisheries Advisory Committee (EIFAC), 1964; Hollis et al., 1964; Lloyd et al., 1987; Newcombe and MacDonald, 1991; Waters, 1995; Anderson et al., 1996; Caux et al., 1997; Birtwell, 1999). There is less information, however, on the specific effects of suspended sediment at relatively low levels (tens of $mg \cdot L^{-1}$) and especially over longer periods of time (weeks and months) (e.g. McLeay et al., 1987; Sigler et al., 1984, Sigler, 1990). More recent studies have focused on the effects of turbid waters on the feeding of fish (Abrahams and Kattenfeld, 1997; Rowe and Dean, 1998; Reid et al., 1999; Vogel and Beauchamp, 1999; Sweka and Hartman, 2001), their migration and avoidance (Boubée et al., 1997; Quigley, 2000), growth (Shaw and Richardson, 2001), and communities (Richardson and Jowett, 2002); and the effects of discharges of fine particulate matter (Davies-Colley et al., 1992) on benthos (Quinn et al., 1992; Shaw and Richardson, 2001).

The water from the Capilano Reservoir that supplies the Capilano Salmon Hatchery is typically of high quality, low in suspended sediment and of high clarity and, consequently, of low turbidity. Accordingly fish at the hatchery are usually acclimated to waters that facilitate good fish husbandry, and any reduction in water quality has the potential to adversely affect these fish. For example, in the winter and early spring 1999 suspended sediment levels in hatchery waters fluctuated and attained peak values of 21 and 26 $mg \cdot L^{-1}$ on February 8 and 25, 1999 respectively (corresponding turbidity values were 18.2 and 23.9 NTU), declining to 3 $mg \cdot L^{-1}$ (4.4 NTU) by April 12, 1999 (Fisheries and Oceans Canada, Capilano Salmon Hatchery, North Vancouver, BC, unpublished data, see Appendix 1, Table A1-1, Figure A1-1). Hatchery staff recorded a decline in food conversion by some fish immediately after they had been exposed to the elevated suspended sediment and turbidity levels (R. Dickson, R. Schrul, Capilano Salmon Hatchery, Fisheries and Oceans, North Vancouver, BC; personal communication). This occurred during a time when the

fish were expected to grow rapidly and consequently some of the hatchery stock did not attain the expected, and targeted, mass prior to their release.

While events such as these were unexpected, they nevertheless indicate the vulnerability of the hatchery fish to adverse changes in the water quality. In this instance relatively low levels of suspended sediment and turbidity seemed to affect the feeding of fish and, consequently, their growth (R. Dickson, R. Schrul, Capilano Salmon Hatchery, Fisheries and Oceans, North Vancouver, BC; unpublished data, see Appendix 1). At the time of release the coho in 18 of 19 (95%) (Table A1-2) holding containers had a mean mass below predicted mass (based on the Capilano Salmon Hatchery Growth Model, modified from Iwama and Tautz, 1981; unpublished data). For further analysis of 1999 data see Appendix 1.

Compounding such concerns over the short-term effects of suspended sediments are the results of analyses by Newcombe and MacDonald (1991). They assessed information on the effects of sediment on different aquatic organisms and described relationships between the duration of exposure to sediment and a "stress index" or "Severity of Ill Effect" (SIE). Newcombe and MacDonald's (1991) analyses determined that by increasing the duration of exposure to a specific concentration of suspended sediment there would be a corresponding increase in harm to the exposed organisms. Through these relationships it is possible to predict that, in general, exposure to a low concentration of suspended sediment for a long time period would result in the same SIE that would occur through exposure to a higher concentration of sediment over a shorter exposure period. The initial concept and analyses of Newcombe and MacDonald were criticized (Gregory et al., 1993). But, further refinement of the data analysis applied to specific groups of organisms resulted in Newcombe and Jensen (1996) revealing that such relationships were valid, and they were especially applicable within the confines of the data used to derive the relationships. The concept was successfully tested in subsequent studies (Shaw and Richardson, 2002; I.K. Birtwell, J.S. Korstrom, Fisheries and Oceans Canada, West Vancouver Laboratory, BC; unpublished data) and incorporated in guidelines for the protection of aquatic resources (Anderson et al., 1996; Caux et al., 1997; British Columbia Ministry of Environment, Lands, and Parks (BCMELP), 1998). Thus, exposure of aquatic organisms over a prolonged period of time to relatively low concentrations of suspended sediment would be predicted to result in a level of harm that was commensurate with the duration of exposure and the level of suspended sediment.

The changes in the quality of water in the Capilano Reservoir over the winter of 2001/2002 that had been identified by Klohn-Crippen Consultants Ltd. (2000) were predicted to have sublethal consequences to fish (such as behavioural responses and physiological stress) based on the analyses of Newcombe and Jensen (1996). However, there are few data upon which to base such a prediction for it is primarily by extrapolation of Newcombe and Jensen's (1996) analyses that one may forecast such effects. Furthermore, exposure of fish to low levels of sediment may be viewed as a minor constraint when compared to the effects of, for example, the exposure of fish to hundreds of thousands of $mg \cdot L^{-1}$ sediment. In the former situation the response of individual fish may be quite variable because of the scope for adaptation, resistance and tolerance which, in the latter case, would decrease with an increase in the severity of the imposed constraint. Applying this notion to the exposure of fish at the Capilano Hatchery it is possible that exposure to low levels of suspended sediment and turbidity may in fact lead to highly variable responses by populations of fish. Responses that are not only difficult to predict through extrapolations of the information presented

by Newcombe and Jensen (1996), but also which may be erroneous because of the imprecision in the model when applied to such low concentrations of suspended sediment and turbidity (a situation that is recognized by the authors). Notwithstanding these concerns, it was impossible to accurately forecast the sediment levels to which fish in the Capilano Salmon Hatchery would be exposed during the winter of 2001/2002. Hence, the prudent approach of Klohn-Crippen Consultants Ltd. (2000) to identify the potential harm to fish, and the necessity of the hatchery staff to respond to such concerns based upon their previous experiences and the need to produce healthy fish stocks, justified a level of concern that merited attention by the GVWD. This report is based on those concerns and the expectation that suspended sediment levels and turbidity of the water entering the Capilano Salmon Hatchery would likely be elevated above background levels at some time during the reservoir draw down period in winter 2001/2002.

The objectives of the study were to determine if exposure to changes in suspended sediment and turbidity adversely affected fish at the Capilano Salmon Hatchery. Because of hatchery requirements to produce fish of a particular size (mass) prior to their release into the Capilano River, and thence to the Pacific Ocean for the marine phase of their life cycle, much attention was focused on growth and feeding, and biochemical indications of the nutritional state of the fish. Growth may be used as an integrative measure of the adaptive responses of the fish to stressful circumstances, and reduced size (for a given age) may increase vulnerability to predators (Parker, 1971; Miller et al. 1988; Gregory and Levings, 1996), aside from any negative effects on fitness and performance that may also occur and jeopardize survival.

Coho salmon (*Oncorhynchus kisutch*) were the species chosen for study, not only because of their abundance at the hatchery, but also because of research that had already been carried out on their responses to sediment and turbidity (which would facilitate an understanding of effects through data comparison). Previous reports have documented that sediment and turbidity can be lethal to coho salmon (Servizi and Martens, 1991; Lake and Hinch, 1999), affect their behaviour (Bisson and Bilby, 1982; Berg and Northcote, 1985), biochemistry and physiology (Servizi 1990; Servizi and Martens, 1992) and growth (Noggle, 1978; Sigler et al., 1984; Sigler, 1990).

The initial experimental design required the exposure of juvenile coho salmon to sediment-free control water and, coincidentally, to the same waters from the Capilano Reservoir with their complement of varying levels of suspended sediment and turbidity. We endeavoured to filter the reservoir water entering the hatchery to provide a sediment-free control source but this was unsuccessful (refer to Appendix 2). It was not possible to remove a sufficient amount of the suspended sediment and the residual turbidity in the filtrate was high. This was likely caused by the clay particles in suspension. In addition, even the most efficient filtration methods employed reduced the subsequent flow of water to a rate that was not practical or tenable for the experiments. Accordingly, the experimental design was changed, and all experimental groups of fish were exposed to the water from the Capilano Reservoir. It was expected that any changes in water quality over the 6.5-month duration of the experiment would be sufficient to result in changes in selected variables that were to be measured over set time periods and around anomalous water quality events. Thus we elected to sample the fish sequentially in the expectation that there would be noticeable cumulative effects and responses by the fish to changes in water quality that would be discernible and predicted from the analyses of Newcombe and Jensen (1996).

The specific objectives of the study were to assess changes in the suspended sediment and turbidity of the water entering the Capilano Salmon Hatchery and their effect on juvenile coho salmon. The components of the work focussed on the growth of populations of fish fed different feeding regimes, the growth of small populations of fish comprised of individually and uniquely-marked fish, the biochemistry of the fish (to reveal their nutritional state and stress), and their behaviour (to assess their escape response to cover - which is compromised by stressful circumstances) during a 6 month exposure period. Details of the methods that were employed are presented below.

MATERIALS AND METHODS

FISH HISTORY

Juvenile Capilano River coho salmon, *Oncorhynchus kisutch* (Walbaum) were used for this study. Fertilised eggs (weighted mean spawning date December 5, 2000) from mid-run adults were incubated, and the hatched fish held, at the Capilano Salmon Hatchery, North Vancouver, BC. On March 14-23, 2001, 39 589 fish (individual mean mass 0.23 g) were moved into aluminum basement trough #5 (identified as Btr 5; 6.4 x 0.80 m; containing 2200 L continuously flowing water) at a loading density of 4.04 $kg \cdot m^{-3}$. Food (EWOS pellet #0, EWOS Canada Ltd., Surrey, BC, Canada) was provided from March 16, 2001 under natural photoperiod conditions. On July 6, 2001, 10 541 coho from Btr 5 (individual mean mass of 1.80 g) were transferred to a large concrete raceway (10.7 x 2.5 x 1.0 m; 25, 400 L) in basement chamber 5 (Bch 5A). On the same day 10 514 coho (mean mass 1.88 g) from Btr 8 were moved to Bch 5B. The fish were fed rations of food in order to achieve particular values at specific dates throughout the year. In anticipation of poor growth coincident with an expected increase in suspended sediment through the 2001/2002 winter, hatchery staff targeted the fish in Bch 5A to have a mass of 12-13 g by September 30, 2001, while those in Bch 5B (which were fed as would occur in a normal year without the anticipated reduction in growth), had the same mass target, but to be achieved by Dec 30, 2001. Both populations of fish in Bch 5A and Bch 5B had targets of 18-20 g to be attained by early June, at the time of their release. Pre-experimental water quality conditions for both Bch 5A and 5B are presented in Tables 1 and 2. Fish from Bch 5A were used in the reported experiments.

TEST APPARATUS

Experiments were conducted in the basement gallery of the Capilano Salmon Hatchery in chamber 3 (Bch 3). The experimental chamber was 11 m long by 5 m wide and was illuminated by fluorescent lights on a natural photoperiod. These lights were activated and deactivated by an outdoor sensor when light and dark thresholds were reached (there was no dawn or dusk control). Water entered the basement chamber at the mid-point of a perimeter Fiberglas head reservoir (Figure 1). This perimeter head reservoir ran along the back and two side walls of the chamber. The head reservoir was drained at the distal ends of each chamber side wall arm (Figure 1).

The experimental apparatus consisted of four rounded bottom aluminum troughs, with volume reduced to 1100 L (from the typical 2500 L; 0.80 x 6.40 m, maximum adjusted water depth 0.25 m) and 10 elliptical Fiberglas 150 L tanks (0.50 x 0.80 m, water depth of 0.50 m). Hereafter these vessels will be referred to as troughs and tanks respectively.

Each trough was supplied with water from the head reservoir by a siphon equipped with a ¾ inch polyvinyl chloride (PVC) valve for setting and adjusting the flow of water. The water flowed by gravitational feed through an aeration bucket containing bio-rings (2.5 cm Flexi-rings, Koch Engineering Ltd., Calgary, AB, Canada) which maximised the surface area of the water for the exchange of dissolved gases with the atmosphere. This step was taken to ensure that the water entering the troughs was air equilibrated and optimal for fish husbandry.

Within each trough, the water volume available to the coho salmon was reduced from 1100 L to 840 L by a divider screen placed 1.50 m from the water inflow, which kept the fish downstream of this turbulent water entry point. The use of the screen facilitated feeding and upkeep of the trough by limiting the area where waste could accumulate and it also held the fish in calmer waters.

Water was drained from the trough at the opposite end to where water entered through a level control standpipe. The fish were excluded from this area by another screen. Flow rate to the troughs was maintained at 20 $L \cdot min^{-1}$ until May 17, 2002 when it was increased to 30 $L \cdot min^{-1}$. These rates were chosen to keep the flow-fish mass-loading density between 0.5 – 0.7 $kg \cdot L^{-1} \cdot min$ in accordance with the recommendations of Sprague (1969) for such studies as were undertaken. Initial flow loading density was 0.52 $kg \cdot L^{-1} \cdot min$, and was increased when the upper limit was exceeded (0.7 $kg \cdot L^{-1} \cdot min$). A rate of 30 $L \cdot min^{-1}$ was set on May 17, 2002 ensuring the flow loading density was below 0.60 $kg \cdot L^{-1} \cdot min$ until the fish were released on June 6, 2002. An opaque Fiberglas sheet placed over 1 m of the downstream portion of the trough provided complete cover for the fish, the remaining length of the tank was semi-covered by a quarter-circular aluminum lid, and open on the other side, though alternate 1 m sections were partially enclosed by plastic anti-predator screens which minimised disturbance of the fish and deterred escape (Figure 1).

The Fiberglas tanks were organised in two rows of five (Figure 1) and positioned in a corner of the basement chamber. They were visually separated from the rest of the chamber by a black plastic shroud from floor to ceiling. This was effected to minimise the disturbance to the fish in these tanks and to equalise the overhead illumination they received.

Each row of five tanks was supplied with water from an elevated 150 L Fiberglas constant head tank that received water from a siphon positioned in the main perimeter head reservoir of the basement chamber. The siphons included a 1 inch PVC valve, which was opened to maintain 30 $L \cdot min^{-1}$ water flow to the constant head tanks. Water supply to the 10 individual tanks was by gravity feed and it was regulated by adjusting a ¾ inch PVC valve within a 1.5 inch diameter, PVC pipe from the constant head tank. During the experimental period the flow rate was maintained at 5 $L \cdot min^{-1}$. Initial flow-mass-loading was 0.046 $kg \cdot L^{-1} \cdot min$, and the loading density was 1.53 $kg \cdot m^{-3}$, both of which resulted in high water quality conditions for the fish and greatly exceeded fish holding criteria outlined by Sprague (1973, 1969). This flow rate achieved a 90% molecular replacement time of 1.2 h. The flow rate was chosen to ensure that the water in the tanks would be replaced rapidly and thereby approximate the natural conditions (regarding suspended sediment) in the Capilano River.

Each tank was covered with a clamped lid (PVC pipe frame covered with 1.0 cm mesh, Vexar® screen to prevent escapement). Half of the lid was obscured with black plastic to reduce visual disturbance of the fish and also to provide them with cover. Water entered each tank through this

Vexar® screen covering, 0.30 m from the edge of the tank. Water exited the tank through a centrally located drain at its base, and an exterior standpipe maintained the water level.

WATER SUPPLY

Water from the Capilano Reservoir, is the main supply of water used for salmon rearing at the Capilano Salmon Hatchery (including the four troughs and ten tanks used in these experiments). The reservoir water is withdrawn through two 1.83 m diameter pipelines. The normal winter operating level of the Capilano Reservoir is between an elevation of 139 and 146 m. The elevation of the intake pipelines for the hatchery supply is at 115 m. During the "East Abutment Seepage Control Program" activities in winter 2001/2002, the reservoir elevation ranged between 118.5 m and 123 m (average 120 m).

Well water was used in the cover response test apparatus used in behavioural studies (details below) to provide a source of water that was of constant quality, of low turbidity, and at a temperature of 8.5° - 9.5° C. This water was drawn from two wells located 1400 m north of the hatchery and on the east bank of the reservoir. The depths of the wells are 121 m and 119 m. Sand filters are employed to remove iron oxide from the well water.

INITIATION OF EXPERIMENTS

Troughs

Sample length and mass measurements of a sub-sample of 100 coho from Bch 5A were determined on November 14, 2001. The result of the sample was an individual mean (± SD) mass of 12.13 (± 3.20) g. On November 15 and 16, 2001, 4000 coho were graded and transferred from Bch 5A to the four experimental troughs in the study chamber. The fish were first restricted by a screen to 2.50 m at the inflow end of the 7.50 m long concrete raceway (5A) to aid the removal of representative samples of fish. Approximately 250 coho salmon were rapidly transferred with a knotless nylon dipnet to a bucket holding 40 L of constantly aerated river water.

The coho were visually graded for a consistent size based on the distribution obtained from length and mass determinations of a sample of fish from Bch 5A on November 14, 2001. The rejected coho were transferred by dipnet to a second bucket containing 40 L of constantly aerated water before their return to that section of Bch 5A which was downstream of the screen. The retained and graded coho were transferred in groups of 25 to the four experimental troughs until each contained 1000 fish.

Tanks

Length and mass determinations on a sample of fish from Bch 5A were determined on November 19, 2001. The protocol for grading and handling the fish was similar to that mentioned previously. The results of determinations on 152 individuals were a mean mass (± SD) of 11.61 (± 3.18) g and a mean length (± SD) of 98.7 (± 7.9) mm. Based on this result, and to be representative of the population, the range of fish accepted for transfer to the tanks encompassed the mean ± 1 SD; a mass between 8.50-14.75 g and a length of 92-106 mm.

On November 21, 2001, the coho were graded according to the above size range in order to minimise any difference in initial size between individual fish and the mean values of fish among

tanks. Fish to be used in the tanks were individually identified through unique tags. Approximately 400 coho were removed with a knotless dipnet from Bch 5A and placed in a container holding 50 L of constantly aerated water. The coho were anaesthetised in groups of 5-10 using a 10 L solution of 50 $mg \cdot L^{-1}$ tricaine methanesulfonate (MS-222; Syndel Laboratories Ltd., Vancouver, BC, Canada) buffered by an equal concentration of sodium bicarbonate. While anaesthetised, length and mass of each fish was determined: those within the chosen limits were individually tagged and length and mass recorded. Any fish not utilized for the study or size-rejected were placed in a recovery bucket holding 50 L of constantly aerated water and returned to Bch 5A, where they were reared by hatchery staff until release.

The graded and retained coho were individually marked with visible implant elastomer (VIE) (Northwest Marine Technology Inc., Shaw Island, WA, USA), injected subcutaneously by syringe and hypodermic needle on the dorsal surface. VIE is a fish-marking material that consists of a two-component biologically inert silicone polymer that fluoresces under ultra-violet light. After the elastomer is mixed with a hardener, it is injected as a viscous liquid, filling the cavity created by a hypodermic needle. Within a few hours the material hardens into a pliable rubber-like mass. The elastomer was one of four colours (green, yellow, red, and orange) and each fish was injected in one of 5 locations, providing a unique identity to each fish in a tank (n=20). After tagging each fish was placed into one of ten aerated 10 L containers to permit recovery, 20 per bucket. The length-mass-tagging time was < 30 s per fish, and the overall duration of the tagging process for 200 fish was 1.5 h. Following recovery from the anaesthetic, all the coho were transferred by dipnet from the 10 L recovery vessels to their respective covered Fiberglas tanks.

WATER QUALITY MONITORING

Several water quality variables were monitored in the troughs and tanks in order to verify that all fish were being held under similar conditions, and also to examine the potential effects they may have on the growth and behaviour of the coho salmon.

Turbidity (NTU) of the incoming water was recorded using a continuously monitoring turbidity meter (Micro 200BW Turbidimeter, HF Scientific Inc., Ft. Myers, FL, USA; precision 0.01%; accuracy ± 2%; range 0-100 NTU). Water supply to the turbidity meter was drawn from the main supply line to the experimental chamber. Turbidity was recorded at 1-h intervals using an analogue data logger (HOBO®, Onset Computer Corporation, Bourne, MA, USA; accuracy ± 1% of full scale, range 0-20.1 mA) linked to the meter. The current (mA) was converted to turbidity (NTU) using the equation: Turbidity = (6.25 x Current) – 25.

Temperature in each trough and tank was recorded at 1-h intervals using temperature loggers (Stowaway® Tidbit®, Onset Computer Corp., Bourne, MA, USA; precision 0.3° C, accuracy ±0.5° C). The logged turbidity and temperature data were downloaded into an Excel file, using BoxCar® (3.6.0.0 ©1999, Onset Computer Corp., Pocasset, MA, USA).

Manual determinations were also made of turbidity (NTU), temperature (° C), dissolved oxygen (DO_2) concentration ($mg \cdot L^{-1}$) and percentage of air saturation, and suspended solids ($mg \cdot L^{-1}$). Turbidity was measured using a portable turbidity meter (Model 2100P, Hach Co., Loveland, CO, USA; accuracy ± 2%, range 0-1000 NTU). The temperature and DO_2 were measured using a

portable DO_2 meter (OxyGuard Handy Mk III, Point Four Systems, Port Moody, BC, Canada; accuracy ± 2%, range 0-50 $mg \cdot L^{-1}$, 0-600%).

Suspended Sediment

Suspended sediment (SS) was determined according to the procedures outlined in: "Standard Operating Procedure for: Non-Filterable Residue (revised May 8, 1998)", Environment Canada Inorganic Chemistry Section, Pacific Environmental Science Centre, North Vancouver, BC, Canada. A brief description is provided:

A water sample, chosen at random, was collected daily from one trough, and another from one tank in each row of five tanks, coincident with determinations of turbidity. These samples were labelled and stored at 4° C until analysis (<7 d). In preparation for analysis, the samples were removed from refrigeration and allowed to equilibrate to room temperature for at least 1 h. Glass fibre filters (1.2 µm, grade 696, 55 mm diameter, VWR Canlab Brand, VWR Canlab, Mississauga, ON, Canada) were dried in an oven at 103° C for 60 min and pre-weighed using an electronic precision balance, (Model BL 120 S, Sartorius AG, Germany; accuracy ±0.1 mg, range 0-120 g). Dried filters were stored in labelled aluminum trays in a dessicator lined with indicating DRIERITE® (anhydrous calcium sulfate, W.A. Hammond Drierite Co. Ltd., Xenia, OH, USA).

The filters were handled with tweezers and carefully placed on a filter assembly. The filtration apparatus consisted of a vacuum pump (Model 2522 WOB·L® Piston Pressure/Vacuum Pump, Welch Vacuum, Thomas Industries, Inc. Skokie, IL, USA), 1000 ml Erlenmeyer filtering flasks, with all-glass funnel/ support assembly; Kontes Ultra-Ware 250 ml bell-shaped top (Cat No. KT953805-0000, VWR Canlab, Mississauga, ON, Canada) and manifold with six attachments. The filters were moistened with distilled water, before the funnel and clamp were placed on top. Each water sample was shaken and divided into two - 100 ml samples in volumetric flasks. Each 100 ml sample was then vacuum filtered and rinsed with distilled water; the apparatus permitted six samples to be filtered simultaneously. Each filter was then carefully removed with tweezers, and replaced on its labelled aluminum tray and dried for 60 min at 103° C before being re-weighed. The difference in initial and final filter mass was then determined and the result expressed as $mg \cdot L^{-1}$ sediment: referred to as the total suspended sediment, or non-filterable residue.

pH, Flow Rate and Total Gas Pressure

The pH and the flow rate of water into each tank were monitored on a weekly basis. The pH was determined with a pH meter (pHTestr, Oakton, Singapore; accuracy ±0.1 pH, range 0-14 pH). The flow rates were calculated using the time, measured by a stopwatch (Model HS-3{V}, Casio®, London, England), to fill a 500 ml Pyrex® graduated beaker. When necessary the rate of flow was adjusted to maintain a constant water replacement time.

Total gas pressure (TGP) was measured periodically in the troughs and tanks using a tensionometer (Model 300C, Alpha Designs Ltd., Victoria, BC; accuracy ±1 mm Hg, range -200 to +700 mm Hg).

Particle Size Analysis

The concentration and size distribution of particles in water entering the experimental apparatus was determined in water samples which were collected on October 30 2001 (2 L, 17.5 NTU), and

on February 5, 2002 (3L, 5.4 NTU). Water was collected from the inflow to the perimeter head reservoir and before its distribution to the experimental troughs and tanks. The samples were analysed by Soilcon Laboratories (Richmond, BC, Canada), using a similar technique to the total suspended sediment analysis procedure described above; however, each sample was filtered multiple times, using filters with four progressively smaller pore sizes (ranging from 20 to 0.47 µm). The particle size distribution and their relative contribution to the total suspended sediment in the sample was obtained through determining the mass of material of different size fractions of sediment that was retained on the filters.

Invertebrates

The invertebrate fauna in water entering the fish exposure apparatus was determined from samples on February 5 and May 14, 2002. This was carried out to determine if there was a significant source of natural food available to the coho that would augment the artificial pelleted food ration they were receiving and confound growth predictions. A 200 µm Nitex® screen was placed on a siphon from the perimeter head reservoir. The water was filtered through the screen for 48 h (20 $L \cdot min^{-1}$; 57 600L filtered in total). The retained material was preserved in a 5% unbuffered formalin solution.

The retained invertebrates were subsequently counted and classified into taxa. A Rose Bengal stain was applied to increase the visibility of invertebrates, and the samples were sieved through a 63 µm mesh screen before being viewed under a dissecting microscope at 35x magnification (Wild M3Z, Leica Microsystems AG, Wetzlar, Germany).

Light Intensity

Light intensity was measured in all tanks to verify that all fish were being held under similar conditions of illumination. Light intensity was measured using a Spherical Quantum Sensor (Model LI-190SB, LI-COR Inc., Lincoln, NE, USA; accuracy: ± 5%). All measurements were taken with the meter set on 1 s, x 1 range at the surface of the water, and in the centre of each tank.

TROUGH AND TANK MAINTENANCE

In accordance with standard hatchery procedure, the bottoms of the troughs were brushed daily to remove any sediment and waste that had accumulated. This involved slowly sweeping the material on the bottom of the tank to the downstream end of the trough using a nylon brush and then removing the downstream level control standpipe. This latter action increased the flow of water draining from the trough and in doing so entrained the waste material. Approximately 400 L of water was drained from the trough during this process.

The tanks were drained and manually scrubbed at three week intervals, while the coho where removed for length and mass determinations. Otherwise, the covers were removed once a week, and the tank bottoms siphoned to remove any accumulated sediment and waste. After siphoning, approximately 75 L of water was drained from the tanks to entrain any waste not removed by siphon, as well as to flush waste from the outlet pipes.

Each week, the water inflow lines to all tanks and troughs were flushed in order to remove any material that may have settled and hindered water flow. This was accomplished by closing all tank

supply valves, the valves were then individually opened, increasing water velocity through the valve and flushing out any residual material in the pipes.

FEEDING OF FISH

Food was administered to all the experimental fish held in troughs and tanks starting on November 26, 2001. Prior to transfer into the troughs and tanks the fish were fed once a week; their last feeding being November 10, 2001. The first feeding of experimental fish occurred 12 days after transfer to the troughs and 5 days after transfer to the tanks (16 days later). The fish were not fed November 17, 2001 (the next schedule feeding) to allow them to acclimate to their new surroundings as well as to recover from the stress of length and mass determinations as well as that of being moved.

The two food sources used in these studies were: EWOS Brand commercial salmon feed (EWOS #3 crumble, 1.5 shortcut pellet and 1.5 smolt, EWOS Canada Ltd., Surrey, BC, Canada) and freeze dried Pacific krill. The nutrient content of the EWOS feed was: 50% crude protein, 20% crude fat, 1% crude fibre, 11% ash, and 9% moisture. The freeze dried Pacific krill had 65% crude protein, 10% crude fat, 19% crude ash and 5% moisture.

The commercial feed rations were calculated per tank on a weekly basis at the beginning of each week. The daily ration was 50% of full ration (expressed as a percentage of body mass·d^{-1}) according to Stauffer's Feed Table (Personal communication, Reid Schrul, Operations Manager, Capilano Salmon Hatchery, Fisheries and Oceans Canada, North Vancouver, BC, Canada) wherein ration varies in accordance with biomass and mean water temperature. A food ration was calculated specifically for each tank and trough; it is important to note that according to hatchery protocol the daily ration is not delivered 7 d a week as is prescribed by Stauffer's, thus the coho received either 35% or 7% of Stauffer's recommended ration, when averaged over a 7 d period. For fish in the troughs the ration was based on the mean mass of a sample of coho extrapolated for the number of fish in the troughs and predicted mean water temperature. In each of the tanks the known mean mass of all coho was used in the calculation of their food ration. In weeks between mass determinations, a predicted value was used based upon the Capilano Salmon Hatchery Growth Model modified from Iwama and Tautz (1981).

During the study several types of commercial pelleted food was used. The juvenile coho were scheduled to receive EWOS 1.5 shortcut pellet upon initiation of the experiment. However, the slower settling EWOS #3 crumble was used thereby extending the available time for the fish to feed (a precautionary step that was considered necessary in order to facilitate feeding in surroundings where light conditions were much brighter and shallower water than the raceway from which they had been removed). After 10 weeks the coho were given EWOS 1.5 shortcut pellets until they attained a mean mass of 12 g (in troughs and tanks, and in accordance with standard Capilano Salmon Hatchery procedures). Subsequently, the fish were fed rations of EWOS 1.5 smolt.

During the period when the fish were fed EWOS #3 crumble, the food in the troughs was spread on the surface of the water close to the cover, at its downstream end, where the coho salmon typically congregated. The other food types were administered in small amounts underneath the cover. Feedings occurred twice daily with a 2 h or longer interval between them.

The fish in the tanks were fed by unclamping and gently lifting the covers to place food on (#3 crumble), or dispersed over (1.5 shortcut, 1.5 smolt) the surface. When using the latter diets it was administered in two batches, allowing at least twenty minutes between feedings. All possible attempts were made to minimise disturbance to fish 30 min prior to, and following feeding.

Coho in the troughs received one of two different food regimes. Fish in troughs #1 and #2 were fed on an augmented regime, which was the daily ration administered five times per week. In contrast, the coho salmon in troughs #3 and #4 were fed on a normal feeding regime that would be fed to coho at the Capilano Salmon Hatchery when there was no anticipation of elevated suspended sediment which could result in poor growth. As such fish in troughs #1 and #2 were fed the daily ration five times a week, while troughs #3 and #4 received it only once a week for the majority of the study. This ration for the week was then the equivalent of 35% of Stauffer's recommendation for troughs #1 and #2 and 7% of Stauffer's recommendation in troughs #3 and #4. The daily ration of pelleted food delivered to all troughs was calculated in the same manner, thus the feeding treatments among pairs of troughs differed in amount because of the number of days per week it was delivered.

There was only one feeding regime for fish held in the in the 10 tanks. Their regime was administered according the normal (low suspended sediment year) hatchery protocol as was done for fish in troughs #3 and #4, thus for the majority of the experiment they were fed once a week, the equivalent of 7% of Stauffer's Feed Table recommendation. However the fish in tanks, in addition to the commercial food ration, were given an additional 10% by mass of freeze-dried pacific plankton (krill) to supplement the pelleted ration; the krill remained on the water surface allowing the fish a longer feeding time, whereas the pelleted food tended to sink quickly.

With the onset of spring, increasing water temperature, and the approaching date of release in June, the procedure of hatchery staff was to gradually increase the frequency of feeding until all the fish were being fed seven days a week for four weeks prior to their release. In accordance with this change in feeding regime, the fish in the tanks and those in troughs #3 and #4 were fed once per week until April 15, 2002 after which time the frequency of feeding was increased to two days a week. Thereafter, in each subsequent week the frequency was increased to 4, 6 and 7 times per week on April 22, 29 and May 6, 2002 respectively. The fish in troughs #1 and #2 continued to be fed five times per week until April 29, 2002 when the frequency was increased to six days a week to match that for fish in all the other tanks and troughs. Thus, all the fish were fed daily from this date until their release on June 6, 2002 after 203 and 210 days of rearing in the tanks and troughs, respectively.

EXPERIMENTAL SAMPLING PROTOCOL

Growth

Growth (length and mass) of the coho salmon was one of the primary factors that was chosen to reflect the effects of suspended sediment on juvenile coho. The length and mass of individual fish was determined at the start of experimentation and every 21-d thereafter.

Troughs: Due to the large numbers of fish within the troughs a sub-sample size of 50 fish was chosen as representative of the population on each sampling occasion. The natural schooling and cover-seeking behaviour of coho enabled a sample to be easily removed from the middle of the school by a dipnet. Fifty fish were extracted from the group into a container holding 10 L of Capilano River water.

Groups of 5-10 fish from this container were anaesthetised in 10 L of 65 $mg \cdot L^{-1}$ solution of MS-222 buffered with equal mass of sodium bicarbonate. The fish were anaesthetized in <2 min, and were exposed to the anaesthetic solution for no more than 10 min. Each anaesthetized fish was then placed on a measuring board (Code #SB30, Dynamic Aqua-Supply Ltd., Surrey, BC), and its fork length (mm) measured. The fish was then transferred to a shallow container of hatchery reservoir water on a tared balance (Model PG-802S, Mettler Toledo GmbH, Switzerland; accuracy ±0.01g, range 0-810 g) and the fish mass (g) was digitally transferred from the balance directly into Microsoft® Excel® on a laptop computer, via serial interface cable and balance interface software (Balance Link 2.5, Mettler Toledo GmbH, Switzerland). The fish was then placed in 10 L of fresh hatchery water to recover from the anaesthetic. This procedure minimised the time it took to process the large numbers of fish from the troughs and resulted in their return to their trough within (mean ± SD) 29 ± 6 min.

Tanks: The length and mass of each fish held in each tank was determined in random order based on a random number table. Fish capture was facilitated by reducing the volume of water in the tanks. This was accomplished by temporarily removing the level control standpipe until the desired water volume was obtained. A dipnet was used to remove all the fish, which were then placed in 10 L of water within a lidded container.

As was reported for the fish in troughs, these fish were anaesthetized in a solution of MS-222. Each anaesthetized fish was then identified by determining the colour and position of its' fluorescent elastomer tag. Amber eyeglasses and a blue-filtered flashlight (7-LED, Northwest Marine Technology, Inc., Shaw Island, WA) that emitted wavelengths from 450-510 nm were used to enhance detectability of marks. The length and mass were then determined and manually recorded using the same apparatus as reported for the troughs. The fish was then placed in fresh hatchery water to recover from the anaesthetic.

Once all 20 fish from a tank had been identified, measured, and recovered from the anaesthetic they were transported back to, and placed in, their original tank by dipnet, after which the cover was replaced and secured. The fish were out of the tank for a mean time (± SD) 28 (± 5) min. The solution of anaesthetic was replaced after processing 100 fish in order to maintain its effectiveness.

Biochemical Analysis

Sampling: During the 203-d duration of the growth study, ten fish were removed by dipnet from each of the four troughs every 21 d and sacrificed via a blow to the head for biochemical analysis. Length (mm) and mass (g) were determined. The fish were rapidly frozen on dry ice (solid carbon dioxide, boiling point: -78.5° C, melting point: -56.6° C) in airtight plastic bags. This process from sacrifice to freezing took less than 2 min.

Once fish samples had been collected from all four troughs in random order, the frozen samples were taken to the Department of Fisheries and Oceans, West Vancouver Laboratory, West Vancouver, BC to be stored at – 40° C, until transfer by air to the Department of Zoology, Oklahoma State University, OK, USA. Biochemical analyses determined the ratio of RNA to DNA in muscle, the concentration of protein in muscle, and the concentration of triacylglycerol (triglycerides) in the whole body of each fish (Weber et al., 2003). The first five fish of ten collected per trough of samples from the 1st, 3rd, 5th, 7th and 9th collection dates (November 27, 2001, January 8, February 19, April 2 and May 14, 2002 - referred to herein as samples 1 through 5) were analyzed as the procedure is laborious and expensive to conduct. If data analysis had determined the need for finer resolution of the results, the remaining five fish per sample, and all ten fish from the 2nd, 4th, 6th, 8th and 10th sample collection dates would have been processed in a similar fashion. See Table 3 for all sampling dates.

Chemicals: All chemicals and reagents were purchased from Sigma (St. Louis, MO, USA) unless otherwise stated and were of reagent grade or better. The purified calf thymus DNA and calf liver RNA used as standards in this study were tested for purity in a preliminary experiment using nuclease treatment and A260 determination. After DNase treatment of the RNA standard and RNase treatment of the DNA standard, concentrations were 102.0% and 102.8%, respectively, (n=4 determinations) of vehicle-treated standards indicating high purity for both standards.

RNA:DNA Ratio Determination: All solutions and plastics used in RNA:DNA measurement were treated to inactivate RNase contamination with diethyl pyrocarbonate and autoclaved. All bench and equipment surfaces were also wiped with RNase Zap® (Sigma, St. Louis, MO, USA) before each day of experiments. A 40-60 mg portion of fish tail (skin and muscle) was cut at the caudal peduncle and placed on ice in a microcentrifuge tube containing 600 µL of TE buffer (10 mM Tris, 1 mM EDTA; pH = 8.0) plus 0.1% (v/v) RNase Zap®. Samples were finely minced and homogenized for 5 sec on highest setting with a Tissue Tearor (Fisher Scientific, Houston, TX, USA). After 6 µl of 1% sodium dodecyl sulphate was added, samples were shaken by hand and incubated at 65°C for 30 min. Samples were centrifuged at 5200xg for 10 min at 4°C, and the supernatant was removed to a sterile tube. Nucleic acids were semi-purified by adding 0.15 x volume 3 M sodium acetate to the above crude homogenate and 2.5 x volume ice cold isopropanol, mixed by repeated inversion and precipitated for 4 h at -20°C. Tubes were centrifuged 30 min at 4°C and 16,000 x g, the supernatant discarded, the pellet allowed to dry for 10 minutes and the pellet resuspended in 1x volume TE overnight at 4°C. The next day the undissolved pellet was dislodged by tapping the bottom side of the tube, gently vortexed, incubated at 65°C for 30 min to ensure nucleic acids were fully dissolved and stored at -80°C until assay.

Samples, calf thymus DNA standard and calf liver RNA standard were diluted as appropriate with TE plus 0.2 M NaCl for RNA:DNA determination. Two identical microplates (white 96-well fluorescence assay microplates, Nunc, Naperville, IL, USA) were used and 100 µl of samples or standards were added to duplicate wells on each plate. The first plate was used for DNA calculation and had a DNA standard curve with all wells receiving 50 µl of 3 $\mu g \cdot ml^{-1}$ Hoechst 33258. The second plate was for DNA and RNA combined measurement and had both a DNA and an RNA standard curve with all wells receiving 50 µL of 15 $\mu g \cdot ml^{-1}$ ethidium bromide. Both fluorescent dye stock solutions were made in TE plus 2 M NaCl and 2.7$\mu g \cdot ml^{-1}$ heparin sulphate. Plates were mixed

by gently swirling and covered with aluminum foil. Ethidium bromide was read with an excitation wavelength of 544 nm and emission wavelength of 590 nm while Hoechst 33258 was read with an excitation wavelength of 355 nm and an emission wavelength of 460 nm. Sample DNA concentrations were calculated directly from the DNA standard curve and the Hoechst 33258 fluorescence. The expected ethidium bromide fluorescence of the DNA from each sample was then interpolated from the ethidium bromide DNA standard curve and subtracted from the sample's actual ethidium bromide fluorescence. The remaining sample ethidium bromide fluorescence is attributable to RNA and was calculated from the ethidium bromide RNA standard curve.

Triglyceride Concentration Determination: Whole body free glycerol and triglyceride concentrations were determined using a modification of a clinical kit (Sigma, St. Louis, MO, USA) for serum triglycerides. Glycerol was used as a standard (0.8-25 $mg \cdot ml^{-1}$) and was diluted with isopropanol as needed. The fish were finely minced and were homogenized in 2 x volume of distilled water 3 times for 10 s with a Tissue Tearor. This crude homogenate was then diluted 10 x in histological grade isopropanol. Each sample or standard (10 µL) was added to a 96-well microplate in duplicate, 180 µL of GPO-Trinder Reagent A (glycerol kinase reagent and chromogen) was added, plates incubated for 5 min at 37°C with shaking and read at 540 nm to determine the free glycerol in the sample. Then 45 µL of Reagent B (lipase reagent) was added to each well, the plates were then incubated for another 20 min at 37°C with shaking and read a second time at 540 nm. Glycerol in the sample arising from acyl glycerides (mono-, di- and triglycerides) was calculated by subtracting the value determined before the addition of Reagent B from the value determined after its addition. Although the acyl glycerol determined in this method may be from an unknown mixture of mono-, di- or triglycerides, all values are expressed as triolein. This assumption was made since the most common fatty acid in triglycerides is oleic acid and triglycerides are the primary storage lipid in fish, making triolein the major representative acyl glyceride and therefore the acyl glyceride readings were treated as triglycerides.

Protein Concentration Determination: Protein concentration was measured using a modification of the Lowry protein assay method (BioRad DC protein assay, Hercules, CA, USA). An aliquot of the crude sample homogenate prepared for RNA:DNA determination in the dual dye fluorescence assay was used to determine protein in an assay adapted to the microplate spectrophotometer. Samples or standards were diluted with distilled water as necessary before 5 µL was added to duplicate wells on the microplate; bovine serum albumin was used as a standard. Absorbance was read at 590 nm and the protein concentrations derived from the standard albumin curve.

Assay Performance Determination: The efficiency of nucleic acids, protein and triglyceride extraction were determined in separate preliminary experiments using spike-recovery. For RNA and DNA, commercial purified standards were added to separate aliquots of tail homogenate in 20 fold excess of endogenous levels. Spiked samples were homogenized, precipitated with isopropanol, processed as normal and RNA:DNA levels measured using the dual fluorescent dye method. Efficiency of RNA or DNA recovery was expressed as a percent of the original amount spiked in the samples. Spike-recoveries for RNA and DNA were 106.1% and 95.1%, respectively. A similar protocol was followed for protein spike-recovery, except that a 100-fold excess of bovine serum albumin was added before homogenization and protein determination of the spiked crude homogenate. Spike-recovery for protein was 91.5%. For triglyceride extraction efficiency, purified 2-monooleoyl-rac-olein (ICN, Costa Mesa, CA, USA) was added in 10-fold excess of endogenous

levels to a coho salmon carcass before homogenization in distilled water. Spike-recovery for triglycerides was 98.6%.

Intra-assay variability was calculated for each experimental method by calculating the coefficient of variation (mean/SD) among six replicates of a pooled sample performed in the same assay. Inter-assay variability was calculated for each experimental method by calculating the coefficient of variation among six replicates of the same pooled sample performed in two separate assays (n=12, total). Intra-assay variation varied from 2.3% to 6.8%, while inter-assay variation varied from 4.2% to 9.4% in the present study. Parallelism is a measure of the ability of a sample to be accurately measured over the usable concentration range of each experimental method. This was determined by measuring serial dilutions of a pooled sample, performing linear regression and comparing the fitted slope with that of the standard curve using a two-tailed t-test. Acceptable parallelism was determined if the estimated slopes were not significantly ($p>0.05$ in two-tailed t-test) different from each other, and was observed for each assay used in the present study.

Cover Response Trials

Apparatus: This apparatus (Figure 2) consisted of a narrow, shallow Fiberglas tank (0.35 m wide, 3.00 m long), with a water depth of 0.19 m maintained by an inner level control standpipe. The interior surface of the tank was coated with two layers of Multi-Purpose Epoxy Coating suitable for salt or fresh-water immersion (BAR-RUST™ 235, Devoe High Performance Coating, Cleveland, OH, USA). Each end (0.75 m), the sides and bottom of the tank were coated with black epoxy and the centre (1.50 m) of the tank was coated with white epoxy. The surface of the black sections of the tank was also covered using sheets of black COROPLAST™ to occlude light.

The white portion of the tank was illuminated by four 250 W, halogen lights (Model L-845, The Designers Edge®, Bellevue, WA, USA) evenly spaced 1.05 m above the surface of the water.

A digital video camera (MC3651H-2 DSP Monochrome Camera, Pelco®, Clovis, CA, USA) equipped with a variable focus lens (13VD3.5-8 Varifocal Lens, Pelco®, Clovis, CA, USA) was mounted directly above the centre of the tank, with the lens 0.95 m from the water surface. The camera was connected to a computer with a monitor from which each trial was observed in real time. The computer was installed with surveillance software (Mark 4&5 Series Digital Recorder, Opticom Technologies Inc., Vancouver, BC, Canada) that enabled the movements of each fish to be recorded (30 frames·s^{-1}), and stored for retrieval and analysis.

Pre-trial Procedures: The cover response tank was filled with 200 L of well water 48 h prior to each trial to permit thermal equilibration within the cold basement gallery at the hatchery. By taking this precautionary step, the temperature of the well water approached that of the Capilano Reservoir water in the hatchery, which is cooler than the well water during winter.

Forty-two hours prior to a cover response trial, 15 fish were placed in flow-through cages located within each of the troughs. The fish were captured in the same way as reported for length and mass determinations, and placed into the 10 L container and then individually graded and transferred to the flow-through cages by dipnet (the fish were graded to eliminate any abnormally large or small individuals at a ratio of 3:1, accept: reject). The cages were made from 19 L plastic containers with lids. Each container had two opposing rectangles (0.18 m by 0.30 m) of 0.5 cm

Vexar® mesh that allowed the enclosed fish to be exposed to the same quality of water as was the rest of the fish in the trough, and minimised energy utilisation. The fish were not fed between the time of capture and the end of the trial (approximately 46 h, fish in troughs #3 and #4 would not normally have been be fed during this period due to their once a week feeding regime).

The water in the cover response apparatus was aerated overnight, through the use of air stones and pumps (Elite 802, Rolf C. Hagen Inc., St. Laurent, QC, Canada) to ensure an air equilibrated dissolved gas level that would not be an impediment to fish respiration and hence performance. Temperature, dissolved oxygen (DO_2) and turbidity were measured both in the troughs and in the cover response test tank immediately prior to a trial. Light intensity was also measured in the tank prior to the trial, at 0.20 m intervals, and at the black-white interface, along both sides of the tank to document and ensure even light distribution within and among tests; minor adjustments of the light source was made as necessary.

Trial Procedures: Cover Response Trials (CRT) began Jan 31 2002, 71 d from the transfer of the fish into the troughs, and a total of six replicates were conducted every 21-d from that date until May 16, 2002. Ten of the fifteen coho placed in each of the flow-through cages within each trough were used during each trial. Each fish was removed from the cage using a dipnet and placed in a small, opaque, oval Rubbermaid® container with lid, containing approximately 0.4 L of well water equilibrated to basement gallery temperature. The fish was quickly transported to the cover response tank with care taken to minimise its disturbance in the container. The fish was placed in the tank, without handling, by pouring it from the container through a glass funnel (3 cm spout diameter). The person transferring the fish to the apparatus then rapidly moved out of view of the fish in the cover response tank.

Each fish was admitted to the cover response tank in the same central location, 0.75 m from either cover. The time of each fish to reach the cover at either end of the trial tank was determined using a stopwatch (Model HS-3(V), Casio®, England). This time was from water entry and until the fish fully crossed into cover as defined by a line between the white and either of the two black, light-occluded sections.

The same person timed the fish in each trial to eliminate any inherent variation among recorders. The orientation of the fish upon entry (head or tail first) and the direction to which covered end of the tank the fish moved to (left or right) was also recorded. To avoid visual disturbance of the fish during a trial, the recorder observed each fish on a computer monitor that was located out of view of the fish.

After each trial, the fish was removed from the tank by dipnet, and placed (< 30 s) in a lethal solution of anaesthetic (200 $mg \cdot L^{-1}$ MS-222). The length (mm) and mass (g) of the euthanized fish were determined.

Refer to Table 3 for a summary of the sampling schedule for all the parameters that were monitored – water quality, fish size, biochemical analysis, cover response trials.

DATA ANALYSIS AND RESULTS

Statistical software JMP IN 4.0.3, © 2000 was utilised in the data analysis.

WATER QUALITY PARAMETERS

Troughs

Descriptive statistics of the daily turbidity, temperature, DO_2 (% and $mg \cdot L^{-1}$) and weekly pH determinations for each trough can be found in (Table 4). Due to correlations between the various water quality parameters the data was analyzed as a multivariate two-way analysis of variance (two-way MANOVA). The response variables were temperature, turbidity and DO_2 (% and $mg \cdot L^{-1}$); the independent variables were treatment and sampling period. MANOVA generates a Hotelling-Lawley F-test p-value that indicates the source of variation amongst means of a data set, a p-value <0.05 indicates greater variation among means than can be considered random. The Hotelling-Lawley p-values revealed that sampling period was the only significant factor with regard to variation amongst water quality parameters ($p<0.0001$), while there was no significant variation between treatment feeding regimes ($p=0.95$) or troughs ($p=0.06$). Subsequent univariate tests (One-way ANOVA) revealed that turbidity, temperature and DO_2 (% and $mg \cdot L^{-1}$) all varied significantly between the 9 sampling periods ($p<0.0001$ for all of the above univariate tests).

A fifth water quality response variable, pH, was analysed separately as the data was collected weekly as opposed to daily which occurred with the other parameters and thus fewer data points were available for analysis. The pH data was analysed as a split plot in time. This model showed that pH varied significantly between sampling periods, and within feeding regime treatments ($p<0.0001$ and 0.004 respectively) but not within troughs ($p=0.48$). The mean pH values for the two feeding regime treatments were 6.58 (augmented regime) and 6.57 (normal regime) which are both well within levels considered to be appropriate for rearing healthy fish. While these mean pH values may be significantly different statistically they are not considered to be ecologically relevant and would be virtually indistinguishable to the animal. Due to limited variation in the pH data small differences in the data tended to be statistically significantly different.

From the above analysis, it was concluded that the fish in all troughs were exposed to ecologically indistinguishable water quality conditions in terms of turbidity, temperature, DO_2, and pH. While there was no significant difference in water quality between troughs over the 6.5 month duration of the experiments (November 2001 to June 2002), water quality did vary temporally, particularly and as expected, in regard to temperature and turbidity (Table 5, Figure 3). This temporal variation was expected as the experiments spanned the seasons from late fall to late spring inclusive.

Temperature : Temperature in the troughs at the start of experimentation (November 22, 2001) was 7.1° C and declined steadily until December 27, 2001, when it reached a low of 2.1° C (Table 4 and 5, see also Figure 3). Temperature then increased to 3.7° C on January 9, 2002, but thereafter declined to a minimum of 1.5° C January 29, 2002. The temperature fluctuated between 2° and 3° C until March 19, 2002 before increasing. By April 11, 2002 temperature had risen to 4.6° C, followed by a brief period of cooling which ended on April 16, 2002 at 3.3° C, from this date onwards temperature rose again with some minor variation and at the end of these experiments it

was 6.6° C (May 30), and 7.4° C on June 4. Mean (±SD) temperature over the entire study was 4.0° (±1.8°) C. Descriptive statistics for temperature data logged hourly reflected a similar pattern with an overall mean (±SD) of 4.28° (±1.85° C), see Table 6. Student's t-tests revealed that each subsequent sampling period had a significantly different mean temperature than the one preceding it ($p<0.05$).

Turbidity: Turbidity in the troughs at the start of experimentation was 11.40 NTU, it then declined to 2.74 on December 13, 2001 before peaking at 17.00 NTU on December 17, 2001. Turbidity then declined again to 3.70 NTU on January 4, 2002 and reached its maximum January 9, 2002 at 17.50 NTU. Another low was reached February 4, 2002 at 2.04 NTU, and turbidity again spiked to 10.90 NTU on February 22, 2002, it then declined to 1.93 NTU on April 10, 2002. A moderate spike in turbidity occurred April 16, 2002 (7.68 NTU) and turbidity reached its minimum May 28, 2002 at an NTU of 1.08. Mean (±SD) turbidity for the length of the study ranged between 5.75 (±4.01) and 5.81 (±4.13) NTU for all of the troughs. See Tables 4 and 5. Student's t-tests revealed that each subsequent sampling period had a significantly different mean turbidity than the one preceding it ($p<0.05$).

Dissolved Oxygen: DO_2 (% and $mg \cdot L^{-1}$) sampling period means for all four troughs combined ranged from 94.3 to 100.3% and between 11.7 and 12.8 $mg \cdot L^{-1}$ and had overall means between 98.0 and 98.6% air saturation (12.36 and 12.43 $mg \cdot L^{-1}$) DO_2. While these between sampling period means were significantly different statistically they were all considered to be well within acceptable fish husbandry guidelines and were not considered to be ecologically relevant to the animal. See Tables 4 and 5.

Tanks

Descriptive statistics were repeated on the water quality data collected for the 10 tanks (Table 7). A one-way MANOVA with turbidity, temperature and DO_2 (% and $mg \cdot L^{-1}$) as response variables and sampling period as the independent variable was used to analyse the tank water quality data. The MANOVA revealed significant Hotelling-Lawley F-test p-vales of 0.0005 and 0.0000 for the variables tank and sampling period respectively. Consistent with the results from analysis of the trough water quality data, univariate ANOVA for the tank water quality data revealed that all four response variables, varied significantly with sampling period ($p<0.0001$). However, only data for mean temperature showed significant variation between tanks. While significantly different statistically the mean temperature values for all tanks was 3.8°C when compared to 1 decimal place which was the precision of the meter used. Therefore, between tanks these values are not considered to be ecologically relevant and would be virtually indistinguishable to the animal. Due to limited variation in the temperature data small differences in the values tend to be statistically significantly different.

A split plot in time was used to analyse pH separately, due to less frequent weekly determinations of this parameter than the daily collection of other water quality data. The analysis revealed no significant variation between tanks ($p=0.53$) and significant variation over sampling periods ($p<0.0001$). The mean pH values for all 10 tanks combined ranged from 6.29 to 6.8 over the 9 sampling periods and were all well within acceptable limits for the rearing of healthy fish. While these mean pH values may be significantly different statistically they are not considered to

be ecologically relevant and would be virtually indistinguishable to the animal. Due to limited variation in the pH data small differences tend to be statistically significantly different.

From the above analysis it was concluded that there was no ecologically relevant variation among any of the water quality parameters between the 10 tanks. Mean values (±SD) for the overall experimental period for all tanks ranged was between 5.66 (±4.02) and 5.74 (±4.04) NTU for turbidity, was 12.4 (±0.3) $mg \cdot L^{-1}$ for dissolved oxygen, ranged between 98.3% to 98.4% (±1.2%) air saturation for DO_2, was 3.9° (±1.7°) C for temperature and was 6.5 (±0.3) for pH. Analysis of temperature data collected from the data loggers produced similar results to the manually collected data with means (±SD) between 4.0° (±1.72°) to 4.1°(±1.69°) C (Table 8 and 9).

While there was no significant difference with regard to overall tank means of temperature and turbidity during the entire period from November 2001 to June 2002 there were significant variations in mean values calculated for these parameters between each sampling date within this experimental time frame. This temporal variation was expected as the experiments spanned the seasons from late fall to late spring inclusive. Table 8 shows the variation in water quality determinations by sampling period. Temperature decreased from 7.1° C at the start of experimentation in November and declined steadily until December 25, 2001 when it reached 2.1° C, temperature then increased until January 10, 2002 when it was 3.7° C before declining to the minimum of 1.5° C on January 29, 2002. Temperature then remained low through February and March (mean monthly values 2.3° and 2.6° C respectively) before it began increasing on March 21, 2002, temperature then rose from 2.4° C to 4.6° C. A brief cooling period followed ending April 16, 2002 at 3.3° C before temperature increased to 6.7° C at the end of experimentation May 29, 2002 (Figure 4). Student's t-test ($p<0.05$) revealed that each sampling period was significantly different than the one previous and subsequent. Similar determinations were made when analysing the temperature data collected from the data loggers (Table 5).

Turbidity was 11.2 NTU at the start of experimentation and declined until December 14, 2001 when it reached 2.64 NTU, followed by a maximum of 19.1 NTU on December 17, 2001 (Figure 4). Turbidity then decreased to 7.51 NTU on January 4, 2002 before peaking again at 18.2 NTU and then declining to 1.97 NTU on February 15, 2002. Turbidity peaked again February 22, 2002 at 11.2 NTU and decreased to 1.75 NTU April 12, 2002. A peak occurred on April 15, 2002 when turbidity reached 7.98 before dropping steadily to the end of experimentation and a turbidity reading of 1.19 NTU. Student's t-test ($p<0.05$) revealed that each sampling period was significantly different than the next in terms of overall mean turbidity.

TEMPERATURE –TURBIDITY RELATIONSHIP

All daily temperature and turbidity measurements from both tanks and troughs were combined to examine whether there was a statistical relationship between water temperature and turbidity. For this purpose a multivariate correlation matrix was constructed which revealed an r-value of -0.33. This is considered near zero and therefore the two water quality parameters were not strongly correlated. An r-value of -0.33 corresponds to an R^2 of 0.11, thus only 11% of the variation in one variable is explained by the other.

SUPPLY LINE TURBIDITY

Descriptive statistics of the logged turbidity data are summarised in Table 10. The overall mean (±SD) turbidity in the supply line to Bch 3 was 6.10(±4.13) NTU, the maximum reading of 42.69 was measured at 02:00 on December 17, 2001 and the minimum of 1.31 NTU was first measured at 11:00 on May 21, 2002 (Figure 5). These data show a much larger range than the manual determinations revealed because readings were recorded hourly, over the 6.5-month experimental period. The continuously logging turbidity meter was therefore able record elevated suspended sediment events more precisely.

SUSPENDED SEDIMENT

The mean (±SD) turbidity of water samples collected from the troughs over the study (November 2001 to May 2002) was 5.78(±4.18) NTU corresponded to a suspended sediment concentration of 2.40(±4.19) $mg \cdot L^{-1}$. The mean (±SD) turbidity of water samples collected in tanks was 5.78(±4.01) NTU which corresponded to a measured mean (±SD) suspended sediment of 2.79(±4.00) $mg \cdot L^{-1}$. As occurred in the turbidity determinations, suspended sediment varied temporally, a plot of the change in suspended sediment over the experimental period is shown in Figure 6 (data from troughs and tanks combined). Samples drawn directly from the Capilano River outside the hatchery were found to have a mean turbidity of (±SD) 8.61(±7.43) NTU and a suspended sediment of 3.83(±6.94) $mg \cdot L^{-1}$ (Table 11). Due to the low turbidity levels of many of the samples collected, it was not uncommon to determine a suspended sediment value that was negative as this routinely occurs due to loss of filter fibres during the rinsing and handling process. In the following statistical analysis any suspended sediment value below zero (84 points) was arbitrarily made to equal zero as negative suspended sediment is not possible, turbidity data was not modified. A standard least squares regression of tank and trough data combined was conducted to test for a relationship between $mg \cdot L^{-1}$ of suspended solids and turbidity (NTU). An R^2 of 0.81 indicates a good fit, with the following equation: Turbidity (NTU) = 2.989 + 0.958 x suspended sediment ($mg \cdot L^{-1}$) (Figure 7).

PARTICLE SIZE

The concentration and percentage contribution of particle sizes in the suspended sediment of 2 water samples are presented in Table 12. The results from a sample taken October 30, 2001, with a turbidity of 16.3 NTU, had a concentration of 20.9 $mg \cdot L^{-1}$ suspended sediment comprising 18.3 %, 46.4%, 32.1% and 3.2% in the > 20 µm, 5-20 µm, 2.5-5 µm and 0.47-2.5 µm particle size fractions, respectively. On February 5, 2002 a sample was taken with a turbidity of 5.39 NTU. This sample yielded 7.8 $mg \cdot L^{-1}$ suspended sediment and particle size fractions of 28.2%, 39.7%, 26.9% and 5.1% in the respective size ranges listed above. Approximate mean particle size based on graphical analysis of this very limited data was 10 and 12 µm for samples taken on October 30, 2001 and February 5, 2002 respectively.

INVERTEBRATES

The macroinvertebrate (> 200 µm) data are presented in Table 13. In February a total of 49 and in May 787 invertebrates were collected in a 48-h collection under water flow to that entering the troughs. This capture of invertebrates resulted in <0.025 and 0.4 invertebrates per fish per day available for consumption during the winter and spring respectively (number of invertebrates per 24 h divided by number of fish in trough - 1000). On both sampling occasions copepods made up approximately 95% of all invertebrates captured. In February turbidity during the test was 5.28

NTU and water temperature was 2.5° C. In May turbidity was 2.03 NTU and temperature was 6.9° C.

LIGHT INTENSITY

With the covers in place there was little variation in light intensity amongst the tanks. On the open side it ranged between 1.02 and 1.33 $\mu E \cdot s^{-1} \cdot m^{-2}$, and between 0.50 and 0.55 $\mu E \cdot s^{-1} \cdot m^{-2}$ under cover; means of 1.19 and 0.53 $\mu E \cdot s^{-1} \cdot m^{-2}$ respectively (Table 14). In the troughs the light intensity ranged from 1.60 to 2.20 $\mu E \cdot s^{-1} \cdot m^{-2}$ at the inflow end of the troughs and between 0.60 and 0.70 $\mu E \cdot s^{-1} \cdot m^{-2}$ under the cover (Table 15).

BASEMENT CHAMBER 5 WATER QUALITY

The mean weekly temperature and DO_2 ($mg \cdot L^{-1}$) determinations in the water entering this location in the hatchery from July 6, 2001 to June 16, 2002 are presented in Tables 1 and 2. The temperature data are the same for Bcm 5A and Bcm 5B and show that from the time the coho were transferred from Btr 5 on July 8, 2001, the temperature increased steadily from 8.0° C to 15.3° C. Temperature then declined steadily until December 30, 2001 when it reached 2.3° C. As was observed in the experimental tanks and troughs, temperature remained low through March 24, 2002, near 2.5° C for this entire period, before increasing again to 7.6° C May 28 (Bcm 5A and B) and to 9.1° C June 18 (Bcm 5A). DO_2 concentration ($mg \cdot L^{-1}$) varied, with temperature. The mean DO_2 concentration was 11.8 $mg \cdot L^{-1}$ equivalent to approximately 98% of air saturation in both Bcm 5A and Bcm 5B, and the mean water temperature of 7.2° and 7.1° C respectively.

FISH SURVIVAL

Despite the handling and other stressful events during the confinement of the juvenile coho salmon utilized in the studies at the Capilano Salmon Hatchery, survival was 99.5% over the 6.5-month experimental period during 2001 and 2002. The population of juvenile coho from the same run, reared from ponding to release over the same time period by hatchery staff, had a survival rate of 94.3%, and the average for juvenile coho from brood years 1995-2000 from ponding to release at the hatchery was 92.1% (Capilano Salmon Hatchery, 2003, unpublished data).

It is usual for some juvenile fish to die whilst held in confinement, and such incidental mortality may be related to the fitness of the individual fish as well as to the stress of confinement, husbandry techniques, and additional handling.

There were no deaths of fish held in the 10 tanks, and only 20 fish died from the population of 4000 that were in the 4 troughs. These incidental deaths occurred in each month of the study, except March and were distributed among all troughs.

LENGTH AND MASS DETERMINATIONS

Troughs

From the length and mass of each fish a Body Condition Index (BCI) was calculated using the following formula: [Mass (g) ÷ (Length (cm))^3] x 100 (Carlander, 1969; Speare and MacNair, 1996). The mean and standard deviation were calculated for each fish length, mass and BCI determination for each trough and on each sampling occasion (Table 16; Figure 8,9 and 10). Figure 11 shows the percentage change in mass over time. This chart illustrates the weight loss that

occurred from the start of experimentation in all troughs, that the coho did not regain their initial mass until March 7, 2002, and there was no appreciable increase over initial mass in troughs #3 and #4 (normal regime) until May 9, 2002.

Due to possible correlation between the various growth parameters a two-way MANOVA was conducted on the length, mass and BCI data with treatment feeding regime and sampling period as independent variables. MANOVA generates a Hotelling-Lawley F-test p-value that indicates the source of variation amongst means of a data set, a p-value <0.05 indicates greater variation among means than can be considered random. This analysis produced a Hotelling-Lawley F-test p-value of <0.0001 for treatment feeding regime and a F-test p-value of <0.0001 for both sampling period and the sampling period-treatment feeding regime interaction term and an F-test p-value of 0.65 for troughs nested within treatment feeding regime. This analysis revealed that there was no significant inter-trough variation but that sampling period and feeding regime did have a significant effect on fish growth and body condition. Further univariate ANOVA tests were conducted to reveal specific differences in length, mass and BCI. Univariate ANOVA for each response (length, mass and BCI) revealed significant variation ($p<0.0001$) for treatment feeding regime, sampling period and the treatment feeding regime-sampling period interaction term and all three responses showed no significant difference in variation for between trough effect ($p=0.83$, 0.57 and 0.68 respectively). Student's t-tests were then applied to the data to reveal any significant differences between fish receiving the two treatment feeding regimes on each of the 9 sampling dates.

Student's t-tests for the length data provided no significant differences between fish in the normal and augmented feeding regimes from the initial determinations on November 22, 2001 until March 7, 2002 when fish fed an augmented ration had mean lengths of 100.7(±4.9) and 100.2(±5.4) mm (trough 1 and 2 respectively) and those fed a normal regime had mean lengths of 98.8 (±6.2) and 99.5 (±5.1) (troughs 3 and 4). However, from this date through the end of the study on May 30, 2002 (Table 16), mean length of the fish fed the normal and augmented ration were found to be significantly different from each other.

A similar multiple comparisons test was conducted on the mass data and these student's t-tests revealed no significant difference in mass initially between fish receiving the normal and augmented regimes in November 2001. However, on December 13, 2001, fish fed an augmented regime were significantly larger (means ± SD: 10.28 ±1.81 and 10.64 ±2.10 g) than those fed the normal regime (10.01 ±1.77 and 9.80 ±1.75 g in trough 3 and 4 respectively). No further significant differences were found between fish receiving the two treatment feeding regimes until March 7, 2002, when the fish fed an augmented regime reached a mean mass of 11.27 (±1.85) in trough 1 and 11.10 (±1.94) g in trough 2 while those fed a normal regime weighed 10.27 (±2.05) in trough 3 and 10.56 (±1.69) g in trough 4. This significant difference in mass remained between fish fed the two regimes until the end of the study in May 2002.

The same multiple comparisons analysis was also conducted on the BCI data. The results paralleled those produced for the length and mass data, revealing no significant differences between the body condition index of fish fed either the augmented or normal ration from November 22, 2001 until March 7, 2002. On this date the fish fed an augmented regime had a mean BCI of 1.09 (±0.08) and 1.09 (±0.06) in troughs 1 and 2 respectively while those fed the normal regime had a

mean BCI of 1.05 (±0.06) and 1.06 (±0.07) in troughs 3 and 4. The mean BCI of fish fed the two regimes then remained significantly different from each other for the remainder of the study.

Statistical Model: A standard least square regression between percentage change in mean body mass per day (mean of 21-d sampling period) and daily percent of body mass ration fed was applied. This model had an R^2 value of 0.683, meaning that 68% of the variation in percentage change in mass·d^{-1} was explained by percentage of body mass ration fed·d^{-1} and that percent of body mass ration fed was highly significant ($p<0.0001$). The plot of residuals versus predicted values were randomly distributed around zero indicating that the data was homoscedastic, and thus the model was valid.

A standard least squares multiple regression was performed on the mean percent change in body mass·d^{-1}. The model included three continuous factors: percentage of body mass ration fed per day, turbidity and temperature (means per trough per sampling period) and a nominal variable of treatment (either normal or augmented food regime). This model showed that temperature, treatment and percent of body mass fed·d^{-1} were all significant ($p=0.0025$, 0.0130 and <0.0001 respectively). Turbidity, elevated though relatively low, was not significant ($p=0.1926$). The R^2 value of this model was 0.784, indicating that 78% of the variation in percentage change in mass·d^{-1} was explained by the variables included in the model. The plot of residuals versus predicted values were randomly distributed about zero indicating that the data was homoscedastic, and thus the model was valid. This model was reapplied, with data from the final two sampling periods during which the feeding frequency was increased excluded. This model resulted in a R^2 value of 0.335, with the only significant factor being temperature ($p=0.0415$).

Tanks

The summaries of the descriptive statistics for length, mass and BCI are shown in Tables 17, 18 and 19. A one-way MANOVA using length, mass and BCI data as the response variables and sampling period as the independent variable was applied to the data collected from fish in the 10 tanks. This analysis revealed significant Hotelling-Lawley F-test p-values of <0.0001 for both tank and sampling period. Further univariate ANOVA tests were conducted on the same response variables using data for each individual fish as opposed to mean values for each tank as was the case with the MANOVA, this analysis revealed that the variables tank and sampling period again had a significant effect. The univariate analysis of BCI and length data returned p-values of <0.0001 for both the variables tank and sampling period, while mass data returned values of $p=0.0006$ for the variable tank and $p<0.0001$ for sampling period. Student's t-tests were then conducted to reveal which tanks were significantly different from each other in terms of the three response variables on any of the 9 sampling dates.

The student's t-tests when applied to fish length data showed no significant differences between fish in the tanks on any sampling date until the final sampling conducted on May 29, 2002. On that date the fish length in tank 9 (mean 108.2 mm) was significantly different than for fish in tanks 1, 2, 5, and 10 (mean values ranging between 111.1 and 111.7 mm). There were no significant differences in fish length between any other tanks on this date. Figure 12 illustrates this difference, as although all fish were reared under virtually identical conditions, the fish in tank 9 appear to have grown more slowly in the final 6 weeks of the study than did fish in any of the other tanks.

The same multiple comparisons analysis when conducted on fish mass data revealed similar results in that there were no significant differences in mass between fish reared in the tanks for any sampling date until the last one on May 29, 2002. On that date the fish mass in tank 9 (mean 13.89 g) was significantly lower than for fish in tanks 1, 2, 5, 8, and 10 (mean values ranging from 15.10 to 15.51 g). Again, although all fish were reared under virtually identical conditions, the fish in tank 9 were, for no apparent reason, more than a gram smaller at the end of the study and appear to have grown more slowly during the final six weeks of experimentation than did fish in any of the other tanks (Figure 13).

The student's t-tests applied to BCI data indicated that there were no significant differences between fish in the tanks when sampled on December 12, 2001, or from the January 23, 2002 sampling date through March 27, 2002. There was a significant difference in BCI on the first sampling date November 22, 2001, between fish in tank 3 (mean BCI value 1.19) and in tank 5 (1.22). On January 2, 2002, the BCI value for fish in tank 1 (1.10) was significantly different than for fish in tanks 6 (1.06) and 10 (1.06). On April 17, 2002 the BCI value for fish in tank 8 (1.09) was significantly different than for fish in tanks 3 (1.05) and 6 (1.05). On May 8, 2002 the BCI values for fish in tanks 2, 3 (both 1.07), 6 and 10 (both 1.08) were all significantly different than for fish in tanks 7 (1.12) and 8 (1.11). On the final sampling date of May 29, 2002 there were fewer significant differences, the BCI value for fish in tank 1 and 8 (both 1.12) were both significantly different than for fish in tanks 3 and 4 (1.07 and 1.08 respectively). Although all fish in the 10 tanks were reared under virtually identical conditions the limited variation in the BCI data for fish between tanks rendered small differences significantly different. Therefore while some of the mean BCI values were significantly different statistically between fish in various tanks, there was a very small range between them and all were within a range deemed to be healthy for the animal and as a result these differences would not be considered to be ecologically relevant or distinguishable.

Figures 13 and 15 illustrate the decrease in the mass of fish that occurred upon their transfer to the tanks both in absolute mass and percentage change in mass from start of experimentation. The first measurable increase in fish mass from the previous sampling was on February 13, 2002 but the fish did not reattain their initial mass until April 17, 2002. From April 15, 2002 forward, feeding frequency was progressively increased in accordance with Capilano Salmon Hatchery procedures employed for troughs #3 and #4, April 29, 2002 for troughs #1 and #2. Consequently there was a rapid increase in the growth rate of fish in all tanks. Figure 12 shows that during the period when fish had a mass that was lower than that at the time of the start of the experiment, that there was very little change in length (approx. 2 mm) from December 12, 2001 to April 17, 2002 followed by a rapid increase until time of release.

At the time of release fish held in tanks had a mean length that ranged between 108.2 and 111.7 mm, a mean mass between 13.89 and 15.51 g (below the target for a mass of 18-20 g) and BCI values between 1.07 and 1.12. (Figure 14).

Statistical Model: A standard least squares regression between percent change in body mass per day (mean of 21-d sampling period) and daily percent of body mass ration fed was applied. This model had an R^2 value of 0.868, meaning that 87% of the variation in percentage change in body mass$\cdot d^{-1}$ was explained by percentage of body mass ration fed$\cdot d^{-1}$, this factor was highly significant ($p<0.0001$). The plot of residuals versus predicted values were randomly distributed about zero indicating that the data was homoscedastic, and thus the model was valid.

A standard least squares multiple regression was also performed on the mean percentage change in body mass·d^{-1}. This model contained three continuous variables: percentage of body mass ration fed·d^{-1}, turbidity and temperature (means per trough per sampling period). This model also had an R^2 value of 0.868, with percent of body mass ration fed·d^{-1} as the only significant factor ($p<0.0001$). The plot of residuals versus predicted values was randomly distributed about zero indicating that the data was homoscedastic, and thus the model was valid. The same model was reapplied with the final two sampling periods excluded (period where feeding frequency was increased). This model resulted in and R^2 value of 0.151, thus only 15% of the variation in % change in mass per day is explained by the model. Both percentage of body mass ration fed·d^{-1} and turbidity were significant ($p=0.0025$ and 0.0203 respectively), however this model is a poor predictor of percentage change in mass·d^{-1}.

Bch 5

Descriptive statistics for the mass determinations on the hatchery-raised fish in Bch 5A and 5B are summarised in Table 20. Just prior to experimentation, on November 4, 2001, the hatchery staff determined that the fish in Bch 5A and Bch 5B had a mean mass of 10.98 g and 11.29 g respectively (based on a bulk mass determination of 100 fish). Our subsequent measurements on November 13 and 19, 2001 determined a mean mass (±SD) of 12.13 (±3.20) g and 11.61 (±3.18) g in Bch 5A (differences probably related to obtaining an accurate and representative sample from 10 000 fish, and different methodology between hatchery staff and ourselves). The fish in Bch 5A were of a greater mass than those in Bch 5B and by March 24, 2002 they were 14.36 g while those in 5B were 10.96 g (Randy Godin, Fish Culturist, Capilano Salmon Hatchery, North Vancouver, BC; unpublished data).

Determinations were made on May 30, 2002 revealed that the fish in Bch 5A met the hatchery release target mass of 18-20 g (18.91 (± 4.33) g); data gathered by staff at the hatchery on June 9 showed a mean mass of 17.76 g. The fish in Bch 5B were last sampled on May 24, 2002 when they had a mass of 15.71 (± 3.17) g; below the hatchery's target for early June. The fish in Bch 5A were fed more frequently (an augmented regime) in anticipation of the effects of elevated suspended sediment levels reducing growth, while those in Bch 5B were fed as they would be in a typical 'low suspended sediment' hatchery year (i.e. on a normal food regime). Similarly to the feeding regime for fish in troughs #3 and #4, the feeding frequency of fish in Bch 5B was increased starting April 7, 2002, from 1 to 2, then 3, 4 5 and 7 d a week until the time of release. The augmented feeding regime in Bch 5A meant that the fish were fed 3 d a week throughout the winter, and the frequency was increased to 4 d a week March 10, 2002, then to 5, 6 and 7 d a week in subsequent weeks. This regime enabled the fish in Bch 5A on pace to meet the target release mass earlier than June, thus in the last four weeks prior to release their feeding frequency was reduced from 7 to only 2 d a week.

BIOCHEMICAL ANALYSIS

Tissue samples were analysed from 5 fish per trough, collected on November 27, 2001, and January 8, February 19, April 2, and May 14, 2002. For the sake of simplicity they will be referred to as sample date 1 – 5. Data for the fish collected on each sampling occasion from each of troughs #1 and #2 were combined, as were those data for the fish collected from each of troughs #3 and #4 in order to be able to compare the results in terms of a treatment effect for fish fed different

regimes. All data provided in this section represent the mean value (± SE). Data for the mean (± SE) of all pooled trough data per treatment group for each sampling date are presented in Table 21.

Due to potential correlation between the various biochemical parameters, a two-way MANOVA was computed for the data using the response variables of muscle protein concentration, muscle ribonucleic acid (RNA) concentration, muscle deoxyribonucleic acid (DNA) concentration and the muscle RNA:DNA ratio with treatment feeding regime and sampling period as the independent variables. MANOVA generates a Hotelling-Lawley F-test p-value that indicates the source of variation amongst means of a data set, a p-value <0.05 indicates greater variation among means than can be considered random. The Hotelling-Lawley F-test for the analysis of the biochemical parameters returned p-values of <0.0001 for both sampling period and the sampling period-treatment feeding regime interaction term, but was not statistically significant for the treatment feeding regime term alone ($p=0.55$).

A two-way ANOVA was also conducted using sampling period and treatment feeding regime as the independent variables and all of the above mentioned response variables, as well as whole body triglyceride concentration. These tests were done to further examine the particular variation of each biochemical response. The results of this analysis are as follows:

Triglyceride Concentration:

The two-way ANOVA conducted on the whole body triglyceride concentration data determined that neither sampling period nor treatment feeding regime had a significant effect ($p=0.12$ and 0.77 respectively). However, the triglyceride content of fish of both feeding regime treatment groups decreased over the 5 sampling periods. For fish fed a normal regime, triglyceride concentration decreased significantly ($p<0.05$) from 0.78 (± 0.14) to 0.49 (± 0.12) $\mu g \cdot g^{-1}$ by the 4th sample date before slightly increasing to a level of 0.58 (± 0.36) $\mu g \cdot g^{-1}$ by the 5th sample date which was not significantly different than the initial value. For those fish fed an augmented regime the triglyceride concentration fell to a mean of 0.48 (± 0.11) $ng \cdot mg^{-1}$ by the 5th sample date from an initial high value of 0.70 (± 0.12) $\mu g \cdot g^{-1}$. This decrease over time, though similar for both treatment groups, was not a significant change from initial values and may reflect the use, rather than storage of this energy storage molecule, for metabolism and growth.

Protein Concentration:

The two-way ANOVA computed on the muscle protein concentration data determined that neither sampling period nor treatment feeding regime had a significant effect ($p=0.12$ and 0.25). The protein levels in the muscle tissues oscillated over time for both treatment groups but by sample date 5 were lower than initial values. Initial tissue protein concentration for fish fed a normal regime was 41.39 (± 4.98) $\mu g \cdot mg^{-1}$ and that for the fish fed an augmented regime was 40.38 (± 4.32) $\mu g \cdot mg^{-1}$. Final tissue protein concentration for fish fed a normal regime was 39.58 (± 3.54) $\mu g \cdot mg^{-1}$ and for those fed an augmented regime was 36.07 (± 6.89) $\mu g \cdot mg^{-1}$. The lowest protein concentration levels recorded for each treatment group were on February 19, 2002, the 3rd sample date, with a protein concentration 39.14 (± 4.96) $\mu g \cdot mg^{-1}$ for the fish fed a normal regime and 35.57 (± 3.62) $\mu g \cdot mg^{-1}$ for the fish fed an augmented regime.

DNA Concentration:

The two-way ANOVA conducted on the DNA concentration data showed that both sampling period ($p<0.0001$) and the sampling period-treatment feeding regime interaction term ($p<0.0001$) were significant. A student's t-test ($p<0.05$) was then conducted on the data and revealed that on November 27, 2001, which was the first sampling date, the muscle DNA concentration was significantly different between fish in the 2 treatment feeding regime groups. Fish fed a normal regime had a mean tissue concentration of 0.75 (± 0.20) $ng \cdot mg^{-1}$ and the fish fed on an augmented regime had a mean tissue concentration of 1.03 (± 0.23) $ng \cdot mg^{-1}$. The DNA concentration of fish fed the two treatment feeding regimes were also significantly different when sampled on January 8 and again on February 19, 2001.

The DNA concentration of both treatment groups decreased over the 5 sampling periods. For fish fed on a normal regime, DNA concentration decreased, though not significantly over time, from 0.75 (± 0.20) $ng \cdot mg^{-1}$ to 0.59 (± 0.14) $ng \cdot mg^{-1}$ over the 5 sampling periods. For those fish fed an augmented regime, the DNA concentration fell to a mean of 0.64 (± 0.17) $ng \cdot mg^{-1}$ by the 2nd sample date on January 8, 2002, was 0.46 (± 0.13) $ng \cdot mg^{-1}$ by the 4th sample date on April 2, 2002 and was 0.57 (± 0.09) $ng \cdot mg^{-1}$ by the 5th sample date on May 14, 2002, all values were significantly different ($p< 0.05$) than the initial high value of 1.03 (± 0.23) $ng \cdot mg^{-1}$.

RNA Concentration:

The two-way ANOVA applied to the muscle RNA concentration data showed that both sampling period ($p<0.0001$) and the sampling period-treatment feeding regime interaction term ($p<0.0001$) were significant. A student's t-test ($p<0.05$) was then conducted on the data and revealed that on the first sampling date of November 27, 2001, only 5 days after initiation of experiments, the fish fed an augmented regime had a significantly lower RNA concentration of 2.56 $ng \cdot mg^{-1}$ compared to a value of 3.22 $ng \cdot mg^{-1}$ for the fish fed a normal regime. This result is the opposite of what was expected and may have been an artifact of chance and not due to the brief treatment received. Several months later on April 2, 2002, a significant difference between the two feeding regime treatments was also found when the fish fed an augmented regime had an RNA concentration of 2.82 $ng \cdot mg^{-1}$ while those fed a normal regime had a value of 2.16 $ng \cdot mg^{-1}$. The RNA concentration of fish in both feeding regime treatment groups decreased after the 2nd sampling date but recovered to values close to initial values by the 5th sampling date. The RNA concentration in fish fed a normal ration decreased steadily over the first 4 sampling dates from an initial value of 3.22 (± 0.70) $ng \cdot mg^{-1}$ to a value of 2.16 (± 0.32) $ng \cdot mg^{-1}$ which was significantly different than the initial value ($p<0.05$) and last sample date ($p<0.05$). However, by the 5th sample date, the RNA concentration had increased dramatically to a value of 3.25 (± 0.51) $ng \cdot mg^{-1}$, which was no longer significantly different than the initial value. The fish fed an augmented regime showed a significant increase ($p<0.05$) from the initial value of 2.56 (± 0.43) $ng \cdot mg^{-1}$ to a value of 3.38 (± 0.67) $ng \cdot mg^{-1}$ by the 2nd sampling date. After which, as was the case with the fish fed a normal regime, the fish fed an augmented regime experienced a decrease in RNA concentration over the 3rd and 4th sample dates before increasing to a value of 3.03 (± 0.42) $ng \cdot mg^{-1}$ by the 5th sample date. Values from the 3rd, 4th and 5th sample date were not significantly different than the initial sample date or each other. In April and May, when food rations and frequency of feeding was increased for fish in both treatment groups, the RNA concentration also steadily increased in both groups (Table 21).

RNA:DNA Ratio:

The muscle RNA:DNA ratios for the fish fed on a normal regime were relatively constant over the first 3 sample dates with mean (± SD) values of 4.37 (± 0.72), 4.32 (± 2.31) and 4.56 (± 1.16) following which the ratio decreased, though not significantly so to 3.70 (± 0.60) by the 4th sample date. The RNA:DNA ratio then increased significantly ($p<0.05$) between the 4th and 5th sample date to 5.61 (± 0.94). However, this higher ratio by the 5th sampling date was not significantly different than that determined at the initial sampling date.

The mean (± SD) RNA:DNA ratios for the fish fed on an augmented regime with a low value of 2.55 (± 0.46) and a high of 6.50 (± 1.99) were more variable over time than ratios of fish fed on a normal regime. Fish fed an augmented regime had a RNA:DNA ratio of 5.41 (± 0.78) by the 2nd sample date, 6.50 (± 1.99) on the 4th sample date and 5.50 (± 1.40) on the 5th sampling date, all of which were significantly higher ($p<0.05$) than the ratio of 2.55 (± 0.46) determined on the first sampling date. A ratio of 3.29 (± 0.82) on the 3rd sampling date was not significantly different than that determined at the initial sampling date but was significantly different than the ratio on the 2nd, 4th and 5th sampling dates ($p<0.05$).

The two-way ANOVA conducted on the RNA:DNA ratio data determined that there were no significant differences between fish in the two feeding regime treatment groups on the 1st, 2nd, 3rd or 5th sampling date. There was however a significant difference ($p<0.05$) between the treatment groups on the 4th sample date. On April 2, 2002, fish fed an augmented regime had a mean (± SD) ratio of 6.50 (± 1.99) compared with fish fed a normal who had a ratio of 3.70 (± 0.60). By sample date 5, on May 14, 2002, fish in both treatment groups had similar ratios with fish fed an augmented regime having a ratio of 5.50 (± 1.40) compared with fish fed a normal regime who had a ratio of 5.61 (± 0.94). In April, when food rations and frequency of feeding were increased for fish in both treatment groups, the RNA:DNA ratio increased rapidly.

Changes in the muscle RNA:DNA ratio was not attributable to only changes in the RNA concentration or DNA concentration alone. RNA concentrations remained more constant and were not obviously different between fish fed the normal regime and fish fed the augmented regime. However, both the DNA concentration and triglyceride concentration generally decreased concomitantly over the 5 sampling dates.

COVER RESPONSE TRIALS

Digital Video Analysis

The digital recording of each fish in a Cover Response Trial (CRT) was converted into AVI format (a common video file format viewable in Windows® Media Player®) and copied onto compact disc (CD-R). The trajectory of each fish was then viewed from the CD-R and traced by hand onto Mylar transparency film. The path of each fish in the horizontal plane was retraced using a planimeter (Enduro®, Switzerland) to measure the distance travelled (cm). The actual distance travelled by the fish was calculated by the use of a conversion factor of the relationship between size of the trial apparatus, and the computer display (x 5.45). The swim speed of each fish ($cm \cdot s^{-1}$ and in body length $\{bl\} \cdot s^{-1}$) was calculated using the distance travelled, the body length of the fish and its time to reach cover.

Water Quality Parameters

Temperature and turbidity readings taken in the troughs and in the cover response apparatus at the time of trials are presented in Table 22, the temperature of well water in the cover response tank increased from 3.4 to 8.1° C from trial #1 to trial #6 and turbidity ranged between 3.63 and 6.97 NTU.

The mean turbidity of the hatchery's water declined from 9.05 to 6.10 NTU from trial #1 to #6 (mean of daily trough measurements from November 21, to day before each trial). The light intensity data determined at each trial are in Table 23; light conditions were approximately equal across all trials, the mean value at the point of fish entry was 6.53 $\mu E \cdot s^{-1} \cdot m^{-2}$ and decreased to 2.19 and 2.49 $\mu E \cdot s^{-1} \cdot m^{-2}$ at the ends of the tank (designated left and right, respectively).

The mean light intensity measured for each trial ranged from 4.98 to 5.50 $\mu E \cdot s^{-1} \cdot m^{-2}$, with an overall mean value of 5.12 $\mu E \cdot s^{-1} \cdot m^{-2}$.

One-way ANOVA between light intensity and trial #, with position where the measurements were taken in the tank as the blocking factor revealed that both position where the measurements were taken in the tank and trial # had significant ($p<0.0001$) effects on light intensity. The significant result in terms of the position where the measurements were taken in the tank affecting light intensity was expected, as there was a decrease in intensity with increasing proximity to the cover. However, every effort was made to ensure consistent illumination and prevent variation among trials. A Student's t-multiple comparison test ($p <0.05$) revealed that trial #6 (mean 5.50 $\mu E \cdot s^{-1} \cdot m^{-2}$) had significantly greater light intensity than all other trials, and that trial #4 (mean 5.20 $\mu E \cdot s^{-1} \cdot m^{-2}$) was also significantly higher than trials #1,2,5.

Results

The mean results from each trough in each trial are presented in Table 24.

Statistical Model: Six CRTs were conducted over 3.5 months between January 31 and May 16, 2002. During this time the size of fish and the temperature of water in the cover response tank varied. The fish growth varied in response with the water temperature, according to season. To determine if any covariates should be included in the statistical analysis of the CRT data, pair-wise correlations were made between the factors fish length, fish mass, and water temperature and the variables of interest: time to seek cover and swim speed (measured in body length$\cdot s^{-1}$). There was no significant correlation between length and time ($p = 0.65$) or length and speed ($p = 0.26$). Similarly, there was no significant correlation between fish mass and time ($p = 0.52$) or mass and speed ($p = 0.28$). The correlation between the tank water temperature and time was not significant ($p = 0.28$) however the correlation with speed was significant ($p = 0.0004$). Based upon these results the temperature of the test water was included in the model when the variable to be analysed was speed.

Time: A one-way ANOVA was used to compare the results obtained from six CRT using fish from troughs #1 - #4. With respect to the time taken for individual fish to seek cover, ANOVA revealed significant differences in response time between the fish from the four troughs ($p = 0.04$). Because ANOVA does not identify which data sets are different and only that there is at least one

pair of means that is statistically different, multiple comparisons tests using both Student's t-tests and the more conservative Tukey-Kramer HSD tests were conducted.

Both multiple comparisons tests showed that the mean (± SE) cover response time of 2.77 (± 0.24) s and 95% confidence interval (CI) of 2.26 – 3.28 s for fish in trough #2, was significantly different than that for fish from trough #3 with mean time to seek cover of 1.67 (± 0.24) s and CI of 1.16 – 2.18 s.

A mean time to seek cover of 2.29 (± 0.24) s and CI of 1.78 – 2.80 s for fish from trough #1 was not significantly different from that for fish from trough #4 with mean time of 2.18 (± 0.24) and CI of 1.67 – 2.69 s nor was the mean time to seek cover for fish from these troughs significantly different than fish from the other two troughs.

When comparing all data together between trials (as opposed to between treatment groups over trials), there was no significant difference ($p = 0.23$) in the "cover response time" of the fish tested over the 3.5 month experimental period during trials #1 to #6. That is the sequential trials were not significantly different than each other over time and no trends over time were apparent.

As the mean time to seek cover by fish from different troughs receiving the same feeding regime was not significantly different, the data were pooled by treatment for further analysis. The ANOVA showed significant differences ($p = 0.03$) in the time to seek cover between those fish which had been fed once a week (troughs #3 and #4), and those which had been fed five times a week (troughs #1 and #2). Combined data from trough #1 and #2 with a mean (± SE) time to seek cover of 2.53 (± 0.14) s and 95% CI of 2.17 – 2.89 s was significantly different than the combined data for fish from troughs #3 and #4 with mean time of 1.93 (± 0.14) s and CI of 1.57 – 2.29 s.

For reasons that are unclear, during each of the 6 CRTs, the mean time to seek cover for fish from trough #3 was shorter than that for fish from the other troughs, with the exception of fish from trough #1 during trial #3. On average, fish from trough #3 took 24% less time to seek cover than did those from trough #4 (the replicate treatment wherein fish received the same feeding regime). Fish from trough #3 took 27% and 40% less time to seek cover than those fish from troughs #1 and #2 that were on an augmented feeding regime. When the data set for fish from trough #3 was excluded from the analysis, and ANOVA computed on the time to seek cover (data for fish from trough #4 vs. combined data from troughs #1 and #2) feeding regime was no longer a significant variable that influenced time to seek cover ($p = 0.24$).

When the data set for fish from trough #3 was excluded and all the data for fish from the troughs was compared between trials (as opposed to between treatment groups over trials), there was no significant difference ($p = 0.19$) in the time to cover of the fish tested over the 3.5 month experimental period during trials #1 to #6. That is the sequential trials were not significantly different than each other over time and no trends over time were apparent.

Speed: The swim speed of each fish was calculated using the distance travelled and the time required to reach cover. However, in order to facilitate comparisons between feeding regime treatments it was necessary to normalise the data and account for differences in the length of individual fish. For this purpose the swim speed data were converted to body lengths·s^{-1} (bl·s^{-1}). The swim speeds were then transformed using a square root transformation to ensure that the residual

errors were normally distributed; a requirement to ensure a valid analysis. In that temperature and speed were previously determined to be correlated, temperature information for each trial was added to the statistical analysis as a covariate. Whether an interaction existed between temperature and the treatment (fish fed on an augmented vs. normal regime) required clarifying and it was subsequently determined that there was no significant ($p = 0.16$) interaction between temperature and treatment.

There was no significant difference ($p = 0.06$) in the swim speed of fish among the 6 CRTs nor was there a significant difference ($p = 0.06$) in swim speed that could be attributable to the temperature of water in the cover response tank.

One-way ANOVA was applied to the swim speed ($bl \cdot s^{-1}$) of those fish from troughs #1 – #4, over all 6 trials. The results of these analyses revealed a significant difference ($p < 0.0001$) in the swim speed between fish removed from the four troughs. Multiple comparison tests using both Student's t-tests and Tukey-Kramer HSD tests determined that fish from trough #3 with a mean (± SE) swim speed of 6.15 (± 0.26) $bl \cdot s^{-1}$ 95% CI of 5.60 – 6.71 $bl \cdot s^{-1}$) was significantly different than the speed of those fish from the three other troughs. Fish in trough #4, which received the same food treatment regime as those in trough #3, had a mean swim speed of 5.08 (± 0.26) $bl \cdot s^{-1}$ (CI: 4.53 – 5.63 $bl \cdot s^{-1}$). Fish from trough #1 swam at a mean speed of 4.62 (± 0.26) $bl \cdot s^{-1}$ (CI: 4.07 – 5.17 $bl \cdot s^{-1}$) while those from trough #2 had a mean swim speed of 4.43 (± 0.26) $bl \cdot s^{-1}$ (CI: of 3.87 – 4.98 $bl \cdot s^{-1}$).

The mean speed with which fish from trough #3 sought cover was faster than any that of fish from the other troughs with the exception of fish in trough #1 during trial #3. As the speed of fish from troughs #3 and #4, which received the same normal food regime, were significantly different from each other, the data could not be pooled and compared (by treatment) to the combined swim speed data from troughs #1 and #2.

On average, fish from trough #3 were 21% faster in seeking cover than fish from troughs #4, which were receiving the same normal food regime. Fish from trough #3 swam 33% and 39% faster than fish receiving an augmented regime in troughs #1 and #2 respectively. When data for fish from trough #3 was eliminated from the data set and ANOVA re-applied to the remaining swim speed data, it was determined that there was no significant difference ($p = 0.13$) attributable to feeding regime hence the treatment variable of feeding regime was not a significant variable contributing to the swimming speed of the fish.

Orientation : Fish were introduced to the cover response tank through a glass funnel. There was the expectation that the fish would display their typical kinetic behaviour and swim into the current of water exiting the funnel. However, some fish entered the tank head first while others entered tail first. Because of the potential implications of such different modes of entry data was collected that revealed the orientation of the fish. Orientation data indicated whether a fish entered the cover response tank head or tail first, and due to its categorical nature was organized into contingency tables by the treatment factor, which was feeding regime. The fish orientation data from trials #1 – #6 were combined for the 120 fish sampled from troughs #3 and #4 (fed once per week) and also combined for the same number of fish sampled from troughs #1 and #2 (fed five times per week). Pearson Chi-Squared Test Statistics were generated on the frequencies in the two categories of the contingency table to determine if there was a general association. The null hypothesis tested was

that there was no association between the data in the rows and columns or between a fish entering the Cover Response Test apparatus head or tail first and the food regime that it had previously received. If the value of $p \leq 0.05$ the null hypothesis would be rejected and an association would be deemed to exist. The statistics in this instance would not support the conclusion that the fish orientation did not depend on the feeding regime.

Seventy-four fish from troughs #1 and #2 went through the funnel and into the cover response tank head first compared to 89 fish from troughs #3 and #4. This difference was statistically significant ($p = 0.04$), and implies that treatment (i.e. feeding regime) may have influenced the orientation behaviour of the fish entering the cover response tank.

The orientation of the fish from each of the 2 feeding regime treatments was also examined separately. Combining the information for fish from troughs #1 and #2, 74 fish entered the cover response tank head first; significantly ($p = 0.01$) more than the 46 fish that entered tail first. Similarly, 89 fish from troughs #3 and #4 entered the cover response tank head first; which was significantly ($p < 0.0001$) more than the 31 fish that entered tail first.

The orientation of the fish from troughs #1 - #4 was also pooled and analyzed. A total of 163 fish or 68% entered the cover response tank head first; significantly ($p < 0.0001$) more than the 77 fish or 32% which entered tail first.

Direction: In order to reach the cover at an end of the cover response tank, fish had to swim in one of two directions that were 180° degrees opposed (designated right or left). It was assumed if both point of fish entry to the tank and operator procedure were consistent there would be an equal number of fish choosing to seek cover at each end of the tank. Direction data indicted whether a fish swam to the left or to the right after entry to the cover response tank, and due to its categorical nature was organized into contingency tables by treatment factor which was food regime. Data from trials #1 – #6 were combined for the 120 fish sampled from trough #3 and #4 (fed once per week) and for the 120 fish sampled from troughs #1 and #2 (fed five times per week). Pearson chi-squared test statistics were generated on the frequencies in the two categories of the contingency table to determine if there was a general association. The null hypothesis tested was that there was no association between the data in the rows and columns or between the direction of movement of a fish upon entering the Cover Response Test apparatus and the food regime that it had previously received. If the p value was less than or equal to 0.05 the null hypothesis would be rejected and an association would be deemed to exist. The statistics in this instance would not support the conclusion that the fish direction did not depend on the food regime.

Forty-four fish from troughs #1 and #2, swam to the right compared to 46 fish from troughs #3 and #4; the difference was not significant ($p = 0.79$). Seventy-six fish from troughs #1 and #2, swam to the left, compared to 74 fish from troughs #3 and #4; the difference was not significant ($p = 0.79$). Therefore, the results of these analyses determined that treatment (food regime) did not influence the direction that a fish chose to seek cover in the cover response tank.

The direction that fish swam to cover was examined within each treatment group and trial. When the direction data were combined for fish from troughs #1 and #2, 44 fish swam to the right after entry to the cover response tank; significantly ($p = 0.004$) less than the 76 fish that swam to the left.

For the combined data for fish from troughs #3 and #4, 46 fish swam to the right after entry; significantly ($p = 0.01$) less than the 74 fish that swam left.

When the direction data for all fish from troughs #1-#4 were pooled and analyzed, it was found that 90 fish (38%) swam to the right after entry which was significantly ($p = 0.0001$) less than the 150 fish (62%) that swam to the left.

Severity of Ill Effects

Over the course of the experiment the fish in the troughs and in the tanks were exposed to fluctuating levels of suspended sediment and turbidity (Tables 5 and 8; Figures 3 and 4). Because the exposure period was approximately 6.5 months it was anticipated that during this time there may be elevations of turbidity and suspended sediment that might have an adverse effect on the fish over the short-term, and cumulatively over the experimental period. The equation [SIE = 0.7262 + 0.7034 (ln hours) + 0.7144 (ln concentration {$mg \cdot L^{-1}$})] of Newcombe and Jensen (1996) that relates to the effect of sediment (0.5 - 75 µm particle size) on juvenile salmon was the most appropriate to use and it was applied to the suspended sediment data.

SIE values were calculated for the periods between determinations of fish growth (troughs and tanks) to reflect the possibility of short-term harm to the fish, and also for the cumulative exposure from the initiation of the experiment. The results of these calculations of SIE applied to these periods of exposure to fluctuating levels of suspended sediment are presented in Tables 25 and 26.

The highest mean level of suspended sediment determined in the troughs was approximately 9 $mg \cdot L^{-1}$ was (n=146, for whole experiment) in December and early January. Suspended sediment concentrations were 2 $mg \cdot L^{-1}$ in November, late January, February and early March, thereafter decreasing to values <1 $mg \cdot L^{-1}$. As expected the predicted SIE values reflected the exposure to the variation in suspended sediment (exposure period was 504 h between sampling periods, and therefore a constant) and the highest values corresponded to the period of exposure to the highest suspended sediment levels. A level of 6.7 was the highest, and approximately 4 the lowest predicted SIE.

Because duration of exposure is a factor related to the SIE, through the course of the experiment the predicted SIE increased. For fish in the troughs the predicted SIE ranged from approximately 6 after exposure to 504 h from the start of experimentation to 7 (1008 - 4536 h; refer to Table 25).

The predicted SIE values based on analyses of the water in the tanks containing individually marked fish followed an almost identical pattern to that for the troughs (Table 26).

Generally declining levels of suspended sediment after late January countered the increased duration of exposure and resulted in predicted SIE levels remaining around 7 from December until the end of the experiment in May.

DISCUSSION

GENERAL CONSIDERATIONS

It was expected that maintenance activities on the Cleveland Dam during the winter of 2001/2002 could result in the deterioration in the quality of water within the Capilano Reservoir (Klohn-Crippen Consultants Ltd., 2000). This deterioration was expected as a consequence of the reduced volume of the reservoir, soil erosion and the washing of material from the reservoirs' exposed shoreline, and unexpected events such as landslides. As a consequence, it was anticipated that the levels of suspended sediment and turbidity in the reservoir could be elevated to levels that would potentially affect aquatic organisms exposed to these conditions. Of particular concern was the maintenance of the health of salmon and trout at the Fisheries and Oceans Canada Capilano Salmon Hatchery, a facility that rears these fish in waters drawn from the Capilano Reservoir.

WATER QUALITY

With the exception of seasonal changes in temperature and minor changes in suspended sediment and turbidity, there was little variation in the quality of waters from the Capilano Reservoir that were used in the experiments. At no time did these variables reach values that would have been stressful to the fish held at the hatchery, and but for suspended sediment and turbidity they were considered to be optimal for the fish.

Dissolved gases in the waters to which the coho salmon were exposed were optimal for the maintenance of their health and fitness. At all times the DO_2 content of the waters was close to 100% air saturation.

We have previously determined avoidance reactions of juvenile chinook salmon at relatively high concentrations of DO_2 (around 8 $mg \cdot L^{-1}$), which approximated the onset of blood hypoxia (about 75% of air saturation) (Birtwell and Kruzynski, 1989). Much lower DO_2 levels have been shown to be stressful to lethal to juvenile salmon (refer to Davis, 1975). In accordance with these determinations of DO_2, levels of Total Gas Pressure were also close to 100%, and at no time were elevated to harmful values (e.g. $\geq$ 110%, sea level, shallow water, Fidler and Miller, 1997; Antcliffe et al., 2002). Similarly, values of pH varied slightly, and lay within 1 unit of the neutral value of 7.

Changes in temperature reflected seasonal climatic conditions and accordingly decreased from about 7° C in November 2001 to a low of 1.5° C in the winter and rose again in the spring to 6.6° C by the end of the experiment in May, 2002. The responses of fish to temperature has been studied extensively due to its' fundamental importance in the life of poikilothermic aquatic organisms as a controlling, limiting, and directive factor (Brett, 1952; Reynolds, 1977; Coutant, 1987). The optimization of metabolic performance is linked to the opportunity for behavioural thermoregulation and the temperature preferred by juvenile salmon generally lies around 16° C (Brett, 1952). This response, however, is influenced by food: a lower thermal preference being associated with less food availability (Brett, 1971; Magnuson et al., 1979; Coutant, 1987).

The food intake and activity of juvenile salmon generally decreases in response to decreasing water temperature in winter (Emmett et al., 1996). Accordingly, fish held at the Capilano Salmon Hatchery received a less frequent and reduced food ration during the winter. In response to increasing temperature in the spring and the corresponding increasing metabolic demands of the fish, the frequency of feeding and the food rations were increased.

SUSPENDED SEDIMENT AND TURBIDITY

Suspended sediment and turbidity in Capilano Salmon Hatchery waters were elevated during the winter experimental period. Such elevations were expected during this time due to the natural influence of rainfall and the associated increase in land drainage and erosion into the Capilano River, aside from responses to periodic landslide events and winter storms. We did not ascertain the source of the elevation in these variables, but their relatively low values and the short duration of them inferred a natural cause and not necessarily one related to construction activities *per se*. The relative elevation in these variables was primarily confined to December 2001 and January 2002 when the peak values of 17.9 NTU and 19.7 NTU were determined in the trough and tank water, respectively. Peak turbidity readings coincided with the two wettest months of the study period with 362.5 mm of precipitation in December and 347.2 mm in January, 13.6 and 44.8 mm above 30 year averages respectively (Table 27) (North Vancouver Cleveland Weather Station Data, Environment Canada, 2003). Minimum values were 1.12 NTU, and 1.13 NTU (troughs and tanks respectively, Table 11). The mean turbidity over the 6.5 month study was 5.78 NTU. Over the same time period the mean suspended sediment concentration was determined to be 2.73 $mg \cdot L^{-1}$ and 3.03 $mg \cdot L^{-1}$ for and maximum values were 18.5 $mg \cdot L^{-1}$ and 17.5 $mg \cdot L^{-1}$ in the trough and tank water respectively.

The turbidity and suspended sediment samples that were taken directly from the Capilano River differ from those that were determined in the hatchery troughs and tanks. In the river the maximum values of turbidity and suspended sediment were higher at 42.6 NTU and 43 $mg \cdot L^{-1}$ respectively, and correspondingly mean values were 8.61 NTU and 4.08 $mg \cdot L^{-1}$. Minimum values were 1.54 NTU for turbidity and below minimum detection level for suspended sediment concentration.

The differences between the determinations in the river and in tank and trough water likely relate to the different drainage inputs between the hatchery source in the Capilano Reservoir and the river sampling location, and the depth of the hatchery intake which is removed from surface waters. Similar differences in the turbidity of the waters in the river and hatchery were recorded in 1999 (Appendix 1, Table A1-1).

The values determined in the troughs and the tanks within the hatchery were similar to those which were predicted (Klohn-Crippen Consultants Ltd., 2000). The time periods over which the data were gathered and those for the predictions differ and, therefore, might account for the differences realized.

Klohn-Crippen Consultants Ltd. (2000) forecast for turbidity to be elevated to 9 NTU and suspended sediment to 9 $mg \cdot L^{-1}$ during the seepage control project. The values determined in the trough and tank water were approximately 3 NTU and 6.5 $mg \cdot L^{-1}$ less than those predicted.

However, a mean turbidity value of 6.10 NTU was obtained for data gathered at hourly intervals (ca 4500 determinations) in the waters entering the experimental chamber at the hatchery. The mean value was only 2.90 NTU less than that predicted by Klohn-Crippen Consultants Ltd. (2000). Mean and maximum turbidity levels determined in samples of Capilano River water were 4.09 and 43 NTU respectively (refer to Table 11). The lower values of turbidity in the experimental troughs and tanks are most probably a consequence of the settling of particles within the apparatus as well as the less frequent sampling of the tank and trough waters.

No extreme elevation in turbidity or suspended sediment was determined during the experiment at the hatchery. Turbidity data that were gathered hourly on the incoming water to the experimental chamber provided more information on the variation that occurred than did the samples that were taken manually. The highest turbidity value was 42.6 NTU (approximately 40.9 $mg \cdot L^{-1}$) which was recorded as a very brief "spike" within a 2-h period. Greater elevation of suspended sediment, to 50 to 180 $mg \cdot L^{-1}$ has previously been associated with landslide events in the watershed (Klohn-Crippen Consultants Ltd., 2000).

PREDICTED SEVERITY OF ILL EFFECT (SIE) SCORES

Elevated levels of suspended sediment and turbidity have been documented to adversely affect salmon and trout, but such levels would typically exceed those that were predicted or anticipated to be in the Capilano Reservoir and River waters during the winter 2001/2002 (Caux et al., 1997; Birtwell, 1999). However, because the level of harm to fish is a function of not only the concentration of suspended sediment (and turbidity) but also the duration of exposure to these variables, it is plausible for exposure to relatively low levels of suspended sediment for protracted periods of time (months) to exert a harmful effect. Newcombe and MacDonald (1991) and Newcombe and Jensen (1996) derived models based on data that describe the effects of suspended sediment on a range of organisms and various groupings of fish and life cycle stages, respectively. Their data analysis identified that increasing harm to aquatic organisms would occur with increasing duration of exposure to suspended sediment. These levels of increasing adverse effects were named "Ill Effects" and were ranked according to increasing severity of ill effect (SIE) from 1 to 14. Levels 1-3 were classified as behavioural, >3 to <9 sublethal, and >9 lethal effects.

Such a forecast of harmful or ill effects presupposes that the model of Newcombe and Jensen (1996) is valid for the prediction of effects, but the data upon which the model is based does not include information on the effects of a 6.5 month exposure to the low levels of suspended sediment that were recorded at the hatchery during winter 2001/2002.

Most of the data in the model used to generate the equation that was used to calculate the SIE for juvenile salmonids exposed to particles of sediment 0.5 to 75 µm in size is based upon the exposure of juvenile salmonids to suspended sediment concentrations in the hundreds to thousands of $mg \cdot L^{-1}$, and only 2 data records describe the effects for concentrations < 20 $mg \cdot L^{-1}$ suspended matter. From Newcombe and Jensen (1996) these records pertain to the exposure of juvenile chinook salmon to 6 $mg \cdot L^{-1}$ lime neutralized ferric hydroxide (MacKinlay et al., 1987) and are, therefore, different to the natural sediment particles that the fish were exposed to during the experiment at the Capilano Salmon Hatchery. Exposure to the ferric hydroxide was determined to have reduced the growth rate of juvenile chinook salmon (SIE 9) over a 60 d exposure period.

Thus the prediction of the SIE for the suspended sediment concentrations the fish experienced over the 6.5 month experimental period at Capilano Salmon Hatchery lies outside the confidence of the model and is an extrapolation from data that describe the effects of exposure to much higher concentrations of suspended sediment. When consideration is also given to the confidence intervals around the SIE prediction (see Newcombe and Jensen, 1996), it is apparent that such long-term exposure may result in a broad range of responses. This is in addition to the natural inherent abilities of individual fish to accommodate, tolerate, and resist stresses; abilities which are likely to result in wider variation in the measured responses of populations when the stressful events are at a low level than when the constraints are higher and the scope for adaptation, tolerance, and resistance are correspondingly decreased. That is, at high levels of suspended sediment that could stress or kill fish, one would expect much less variation in response among individuals and, consequently, a smaller 95% confidence interval.

The values of SIE that were calculated for the suspended sediment concentrations to which fish were exposed in the tanks and the troughs reveals that over the shorter duration of exposure (504 h) between sampling periods, the values ranged from approximately 4 - 7 and 3 - 7 for fish in the troughs and tanks, respectively.

Over the study period the cumulative effect of exposure duration was evident, and calculated SIE values ranged from about 6 - 7 for fish in both troughs and tanks. Based on the data of Newcombe and Jensen (1996) the 95% confidence intervals would be about 1.3 to 1.4 SIE units around these values. Accordingly the overall range of predicted SIE scores would encompass levels close to 2 and <9. Such a widespread range of SIE values could be manifest in behavioural (≤3), and sublethal (>3 - <9) responses, but not lethal effects (>9) as identified by Newcombe and Jensen (1996).

Avoidance responses, alarm reactions and abandonment of cover would be examples of behavioural responses, while the responses categorized as sublethal would include reductions in feeding rate and success, and long term physiological stress (Newcombe and Jensen, 1996).

Reductions in growth rate were considered by these authors to be in the lethal category (reduced feeding leading to reduced growth rate and implications to reduced survival in the wild typically through increased predation of the smaller individuals). Thus the model of Newcombe and Jensen (1996) did not predict reduced growth as a consequence of exposure to the suspended sediment levels experienced by fish at the hatchery during winter 2001/2002.

Although it was not possible in advance to accurately predict the levels of suspended sediment that fish at the Capilano Salmon Hatchery would experience, and therefore the likely consequences of exposure, our experiments utilized three measures that were intended to reveal the consequences of stress and the potential for adverse consequences to survival of fish in the wild.

As a behavioural measure (SIE ≤3), the response of the fish to seek cover (an alarm or fright response) was employed, to examine to potential for reductions of feeding rate (SIE >3 - <9) we used the growth of the fish fed different rations of food (to examine ration and exposure to changing water quality conditions), and biochemical indices to reveal the nutritional state and health of the fish. The following sections discuss the results of these examinations.

RESPONSES OF FISH

Survival

It was expected that some fish would die naturally in the hatchery, and others as a result of the stress imposed through confinement, and general husbandry techniques. In addition, the invasive practices we employed to uniquely mark fish, anaesthetize them and measure their length and mass, and remove samples over the 6.5-month experimental period, could have exacerbated the stress imposed resulting in the death of fish (Wedemeyer et al., 1991). However, there was only incidental mortality of fish over the experimental period, and this mortality was below that experienced for the general population of coho salmon raised during the equivalent time frame at the hatchery.

All the fish that were held in the tanks survived. These fish were subjected to the most severe stress of all the fish used during the experiment as they were initially uniquely tagged, and regularly anaesthetized and handled individually over the 6.5-month period of the experiment.

Survival of fish in the troughs was 99.5%. Only 20 fish died within the population of 4000, that were held in troughs #1-4 (4, 4, 7, and 5, respectively). Two fish died in November, 9 in December, 5 in January, 2 in February, none in March, and 1 in April and May.

The very low and incidental death of a few fish indicates that the water quality conditions and other potentially stressful conditions to which the fish were exposed were not lethal to the majority of the test population, nor were they more stressful than those conditions experienced by the general population of coho salmon raised during the equivalent time frame at the hatchery.

This result, in relation to human interventions and natural factors, was expected as we endeavoured to minimize the stress imposed on the fish. However, in that the effects of stress are cumulative (Wedemeyer et al., 1991), the potential for any handling related stress combined with any that may have occurred due to changes in water quality had the potential to result in mortality. That this was not the case leads to the conclusion that the conditions that the fish experienced during the 6.5-month experiment were not lethal. This result is also consistent with the predictions of SIE based on the model of Newcombe and Jensen (1996). A reduction in the general health of the fish, increased physiological stress, and reduced feeding and poor condition is predicted by the model, but not lethality or reduced growth rate.

Servizi and Martens (1991) determined the lethality of Fraser River sediments to juvenile coho salmon. The concentrations that caused death over a 96-h exposure period were approximately 1000 times greater than the concentrations determined in the waters entering the hatchery during the winter of 2001/2002. Furthermore the effect of suspended sediment on fish has been related to particle size, to the extent that larger particles would have a greater effect (Servizi and Martens 1987). The particles in suspension in the water that entered the Capilano Salmon Hatchery during the experiment were below the 75 µm size criterion used by Newcombe and Jensen (1996) to separate the harmful effects of different particle sizes on fish, and were in the very fine silt category. As such, and because of their small size, they would be less likely to induce harm than would be expected of larger particles.

Growth and Condition

Exposure to suspended sediment has been determined to affect the growth of fish, but no such effect on the growth of coho salmon was apparent based on statistical analyses of the data that revealed the factors most associated with changes in fish mass during the 6.5-month exposure period. This result is in accordance with the predictions of SIE that relied upon data over the shorter between sampling occasion periods and also the total exposure period for fish held in the tanks and in the troughs. Many water quality conditions varied during the course of the experiments, but those factors expected to exert most influence the growth of the juvenile coho salmon were those that displayed the greatest variation, that is, temperature and suspended sediment (and associated turbidity).

Attempts to filter the very fine suspended sediment particles and reduce turbidity in the waters entering the hatchery from the Capilano Reservoir were ultimately successful. However, the apparatus required was not economically feasible or practical to use. Thus we were not able to provide water, free of sediment and turbidity, for use as a control source (refer to Appendix 2 for details). Accordingly, the experimental design was modified. Instead of specifically comparing the responses of the coho salmon upon exposure to sediment and turbidity-free waters (control group) with the responses of fish in waters containing the naturally varying concentration of suspended sediment and turbidity (i.e. the treatment group), we relied on the statistical analyses of data collected over 6.5 months to reveal those variables that most influenced the growth of the fish. It was possible to obtain relevant information by sampling the fish at discrete 21-d intervals during the 6.5-month experimental period. Assessments of effects were made through determination of their growth and condition, biochemical profiling, and behavioural responses. The responses after 21-d exposure periods and cumulatively over the 6.5 months were compared with predicted responses of fish to suspended sediment, based on the SIE model of Newcombe and Jensen (1996). This information was then used in an assessment of likely effects based on existing and relevant literature.

Within the limitations of this experimental approach, it was determined through statistical analyses that the primary variables that influenced the growth of the juvenile coho salmon were temperature and food ration and not exposure to suspended sediment and the associated turbidity of the water. Thus exposure to mean suspended sediment concentrations of 2.7 and 3.0 $mg \cdot L^{-1}$ (troughs and tanks respectively) and a turbidity of 5.78 NTU from November 2001 until May, 2002 did not have a significant adverse effect on the growth of juvenile coho growth relative to the influence of food and temperature.

Klohn-Crippen Consultants Ltd., (2000) forecast reductions in growth of fish held at the hatchery and subjected to slightly higher turbidity and suspended sediment concentrations over a 6 month exposure period. Their predictions relied on extrapolations of data and were, as they realized, subject to error. No data were available that could have been used to accurately predict whether or not a reduction in growth of the fish would occur upon long-term exposure to relatively low, yet slightly elevated, levels of turbidity and suspended sediment. In addition fish husbandry practices at the hatchery are logically responsive to any adverse effects on the growth of their fish. The staff take appropriate action (such as increasing or decreasing food rations and frequency of feeding) to meet the requirement to release fish of a targeted mass in the early summer, and in

doing so add other variables that make accurate predictions of effects based on previous data difficult to make.

Because staff at the hatchery had previously recorded a reduction or cessation of feeding of fish after they were exposed to elevated levels of suspended sediment (21 and 26 $mg \cdot L^{-1}$ on February 8 and 25, 1999 respectively (corresponding turbidity values were 18.2 and 23.9 NTU), declining to 3 $mg \cdot L^{-1}$ (4.4 NTU) by April 12, 1999) and that this had implications to the growth of the fish prior to their release, food ration was chosen as a variable to consider in the experiments. It was expected that changes in growth rate would occur if there was a prolonged (weeks) impairment of feeding due to exposure to changing water quality, but that this may be offset through increased food rations and feeding frequency. In the fall, hatchery staff augmented the food ration of the majority of the fish that they were holding over the winter of 2001/2002 to avoid potential and anticipated negative effects of turbid water on the growth of the fish. Thus they would safeguard against the fish being smaller at the time of their release, than that which was targeted. This is significant as smaller fish size at the time of release can have negative implications to their survival in relation to larger conspecifics.

In the present study, to investigate whether an augmented food ration affected the growth of the coho salmon 1000 fish in each of 2 troughs were given an increased frequency of feeding and hence an augmented food regime. The same numbers of fish in 2 other troughs received the normal regime fed at the frequency used at the hatchery. Daily food ration was adjusted in relation to the growth of the fish and the temperature of the water.

Ten smaller tanks, each containing 20 fish were used to follow the growth of individually marked fish fed in accordance with hatchery procedures, in the expectation and anticipation of effects on feeding and growth that may be manifest under different holding conditions.

Thus we examined the effects of food and ration on the fish while they were coincidentally exposed to changes in water quality (e.g. suspended sediment {turbidity} and temperature) of the waters entering the hatchery from the Capilano Reservoir.

It was also recognized that the natural source of water from the reservoir that entering the hatchery might contain food items for the coho salmon and correspondingly affect food rations and the growth of the fish. However, few food items were found in the water and it was calculated that any increase in food was inconsequential relative to that fed to the fish and amounted to 0.05 - 0.8 food item per fish in 2 d.

Following the initiation of the experiment the temperature of the water to which the fish were exposed decreased and but for minor fluctuations did not increase again until the spring 2002 (Table 5 and 8; Figure 3 and 4). At the same time concentrations of suspended sediment fluctuated and tended to be elevated at the time of declining and low temperature during the winter, but were low in the spring 2002 (Table 5 and 8; Figure 3 and 4). Thus there was the potential for both factors to have an effect on fish growth aside from the food ration and the frequency of feeding. It was determined that temperature and suspended sediment were not statistically correlated with each other and therefore could be used as independent variables in statistical analyses used to identify those variables most associated with changes in the growth rate of the fish. In addition, the

condition of the fish was assessed though the use of the Body Condition Index (BCI) that relates length and mass data (Kiessling et al., 1994; Speare and MacNair, 1996). In this way it was expected that any prolonged and negative effects on feeding due to exposure to elevated levels of suspended sediment and turbidity might be revealed through a loss of condition (also expected from the results of biochemical analyses that were undertaken).

Declining temperature and reduced metabolism and demand for food would have contributed to the maintenance of fish mass, but possibly not its increase, under such low temperature conditions. In that the feeding procedures we employed followed those employed at the hatchery with the exception of fish fed the augmented regime, and not those recommended in ration tables (Table 28 and 29), the fish were fed a minimal quantity of food during the majority of the winter 2001/2002. Interestingly, this minimal ration did not result in a dramatic loss of fish condition, but declines were evident. (Table 16 and 19; Figure 10 and 14). From the start of the experiment the BCI of fish in the troughs (normal food regime) and tanks displayed a trend of decreasing values over time. The BCI of fish in the tanks was approximately 1.2 at the start of the experiment while that of the fish in the troughs was approximately 1.1, a difference attributed to the closer size grading of the 200 fish placed in the tanks for the specific growth study. There were, however, differences in the BCI of fish given the augmented and normal food regimes (see below). It is inferred that such food rations, while not recommended, were at a marginal maintenance level for the coho salmon within the protected and less challenging environment of the hatchery (refer to tables 98 and 99). In the more metabolically and competitive environment of the wild, such a diet would probably be insufficient to meet the fishes needs (such as that required for capturing prey and avoiding predators). For example, at Prince George, BC, the nocturnal juvenile chinook salmon that spend their winter in the Fraser River were determined to contain 0.4 to 2.81% body mass of recently consumed food (Emmett et al., 1996), and this despite the temperature of the river water being <1° C. The lowest temperature of the water in the troughs and tanks was recorded to be 1.5° C (for a very brief period), hence it would have been expected that the metabolic demands of the coho salmon would have been greater than those of fish in water with a temperature of <1° C, and that because of this demand they would have lost condition (BCI) because of the relatively low food ration they were given. Differences in the condition of fish among treatments reveals that this may have occurred for some fish that were not fed the augmented regime.

The sequential determinations of the mass and length of fish during the experiment revealed a general pattern in which fish did not grow or grew little during the colder months of the winter when water temperature was low, and suspended sediment and turbidity relatively low yet elevated over mean values. The fish grew when water temperature, and feeding regimes and rations were increased, and perhaps coincidentally, when suspended sediment and turbidity were at low but declining levels in late spring.

The data for the growth of the fish in relation to food ration, temperature and turbidity (suspended sediment) was subjected to statistical analysis to reveal which factors most affected the growth of the fish. It was determined that for both the fish in the tanks and in the troughs that there was a highly significant relationship between the growth of the fish (% change in body mass·d^{-1}) and their food ration (as % body mass·d^{-1}).

Temperature, treatment feeding regime, and the percentage of body weight fed per day were the most significant variables associated with fish growth in the troughs: elevated though relatively low turbidity (suspended sediment) did not have a significant effect. It is therefore not unexpected that those fish fed an augmented regime of food over the experimental period were longer (by approximately 6.5 mm) and had a greater mass (by approximately 3 g) than those fish fed a more restricted food regime according to normal hatchery practices.

Calculations showed that fish fed the augmented regime of food had a significantly higher BCI than those fish fed the more restricted regime until the feeding regime was changed in the spring 2002. The BCI of fish on the more restricted regime increased in response to the increased feeding frequency in April, but at the end of the experiment those fish that had been fed the augmented regime of food had a slightly higher BCI. The BCI of salmon is typically above 1 and varies in response to food supply (Kiessling et al., 1994). Fish that gain mass more so than length have the greater BCI, thus the BCI is an indication of the ability of the fish to allocate food to increase body mass which, in turn, is a reflection of food supply, and its conversion. There was no evidence of an increasing trend in the BCI of the coho salmon in the troughs yet there was a general decline from Novemeber into February for those fish on the augmented food regime, and until April for those fish on the normal ration.

The results of statistical analysis revealed that the condition index of fish on the augmented food regime was less affected over the duration of the experimental period than that of fish given the normal food regime. In all treatment groups the BCI was significantly lower during the winter. This was also a time when there was most change in water quality; temperature decreased to minimal levels and increases in suspended sediment and turbidity occurred (mid December to February).

The exact significance of these trends are unclear, but the inference is that food ration was insufficient to maintain or increase the BCI of some fish during the winter period of the experiment. Whether such BCI values have biological significance to the well being and survival of the fish in the wild is difficult to predict. The results of the cover response test revealed that the fish quickly fled to cover, implying no impairment of this adaptive and significant flight response, despite any changes in BCI over time and between treatments. However, this response is primarily an anaerobic activity (Brett, 1964) that is susceptible to the detrimental influences of stressors (Sigismondi and Weber, 1988). The demand for repeated similar responses when fleeing to cover or capturing prey, together with sustained swimming activity require that the nutritional status of the fish be maintained to meet these metabolic demands in the wild. In the protected environment of the hatchery, the metabolic demands on the fish are less than that in the highly competitive environment of the wild. Accordingly it would be expected that fish in the wild would have a BCI related to nutritional state, growth, and metabolic needs that may differ than that determined for fish in the relatively protected hatchery environment. That said, there might be species-specific differences in the condition indices of fish as well as changes in relation to metabolism and food conversion. McLeay et al., (1987) determined that the condition index of juvenile Arctic grayling during a 6-week laboratory experiment was similar to that of Arctic grayling captured in the wild (Birtwell et al., 1984). These indices were less than 1. Speare and MacNair (1996) recorded a mean condition index for rainbow trout of 1.14 in laboratory experiments that assessed the growth of the fish in relation to the therapeutic effects of formalin. Kiessling et al. (1994) determined the condition index of juvenile chinook salmon to range from 1.14 to 1.4 in laboratory experiments that

assessed the growth of salmon given a recommended food ration, and from 1.14 to 1.30 for fish fed 75% of this ration over 212 d.

The same analysis applied to the data for fish in the tanks determined that the food ration was the most significant variable related to growth and that neither temperature nor turbidity (suspended sediment) had a significant effect within the range of conditions experienced. As was the case for the fish in the troughs those fish held in tanks responded to the increased feeding regime and ration in the spring, and commenced relatively rapid growth. Not unexpectedly, the final length and mass of fish in the tanks prior to their release was similar to those of fish fed on the same regime within the troughs. Thus, and again, the food regime played a significant role in influencing the growth of the fish in contrast to other variables.

The growth data recorded in the hatchery for stock fish in Basement Chambers 5A and 5B (augmented regime, and normal regime respectively) also reveal the influence of food ration on the growth of the coho salmon over winter 2001/2002. Hatchery staff augmented the feeding regime of food to fish in Bch 5A and by March, 2002 these fish were approximately 3.4 g more than fish from Bch 5B. The extra ration of food given to the former stock of fish was in anticipation of reduced feeding and consequently reduced growth due to elevated levels of sediment and turbidity as occurred in 1999 when the reservoir was drawn down (personal communication, Reid Schrul, Operations Manager, Capilano Salmon Hatchery, North Vancouver, BC; unpublished data; Appendix 1).

Deductions from Results: While recognizing the limitations of the experimental design to definitively isolate those variables that affected the juvenile coho salmon during the 6.5-month experiment, it was nevertheless possible to deduce their relative influence. In this regard there was no apparent negative effect due to variations in water quality that were discernible on the growth of those juvenile coho salmon held at the hatchery as stock fish, or on those used in the experiments during the winter 2001/2002.

These results are consistent with the predictions of Newcombe and Jensen (1996) regarding exposure to suspended sediment, even though one cannot place too much confidence in the use of the model in this circumstance. This is because the suspended sediment concentrations were, overall, lower and outside of the data boundaries used to construct the model. To our knowledge there are no comparable data with respect to the exposure of juvenile salmonids to suspended sediments and turbidity with which to compare the results we obtained.

The concentrations of suspended sediment (and turbidity) to which the fish were exposed were low compared to those that have been determined to affect the feeding and growth of coho salmon and elicit other negative effects. For example, Noggle (1978; cited by Newcombe and Jensen, 1996) determined that the feeding of juvenile coho salmon decreased when exposed to 25 $mg \cdot L^{-1}$ suspended sediment, and ceased at 300 $mg \cdot L^{-1}$.

The most relevant research to that carried out at the Capilano Salmon Hatchery was that of Sigler et al. (1984). They exposed juvenile coho salmon (and steelhead trout) to different levels of suspended sediment/turbidity through additions of clay to artificial channels and raceways. They determined that juvenile coho salmon had a reduced growth rate when exposed for 336 h to suspended sediment concentration of 102 $mg \cdot L^{-1}$, and that a turbidity level as low as 25 NTU

caused a reduction in the growth of the fish (NTU = 10.0 + 0.178·mg·L^{-1} for suspended material in the water; NTU = 5.49 + 0.162·mg·L^{-1} bentonite clay). While this level of turbidity is higher than the maximum value recorded in the waters of the troughs and the tanks, a maximum value of 42.69 NTU (02:00, December 17, 2001) was recorded (data logged hourly) in the incoming water to the experimental troughs and tanks (Figure 6). Overall, however, elevations in suspended sediment and of turbidity were transient and mean values were substantially lower than those that Sigler et al. (1984) determined to have an effect of the growth of juvenile coho salmon.

Other researchers have determined the effects of suspended sediment and turbidity on the growth of salmonids, but in all instances the effects on growth and feeding were at levels higher than the mean and the maximum values recorded in the tanks and the troughs. For example, McLeay et al. (1987) determined that exposure of juvenile Arctic grayling to sediment concentrations at and above 100 mg·L^{-1} to 1000 mg·L^{-1} resulted in reduced growth rate relative to controls over a 6-week period, and that the results were correlated with reduced feeding efficiency in the turbid waters. Juvenile chinook salmon exposed over 3 weeks to suspended sediment concentrations of 100, 300, and 1000 mg·L^{-1} (approximately 120 -1200 NTU) were also found to have reduced growth relative to those fish in control waters[1]. The results were commensurate with exposure to the concentration of suspended sediment. In addition the feeding of these fish on surface prey was affected in a dose-dependent manner, and duration of exposure (to 9 weeks) resulted in a greater impairment in feeding efficiency (I.K. Birtwell and J.S. Korstrom, Fisheries and Oceans Canada, West Vancouver Laboratory, West Vancouver BC; preliminary assessment of unpublished data).

Even data on the sublethal and behavioural effects of suspended sediment on juvenile salmonids utilized, and referred to, concentrations of suspended sediment and turbidity that were typically higher than those to which the fish at the Capilano Hatchery were exposed in the winter of 2001/2002 (refer to Anderson et al., 1996; Newcombe and Jensen, 1996; Caux et al., 1997; Birtwell, 1999).

Based on the foregoing comments and information, it is not surprising that there was no evidence of adverse effects on the growth of fish during the 6.5 month exposure period that could be attributed to exposure of the coho salmon to suspended sediment and/or turbidity. This deduction is further reinforced by the opinion of C. Newcombe (British Columbia Provincial Government, Victoria, BC; personal communication) who stated that any effects of the elevation in suspended sediment and turbidity on the coho salmon that may have occurred would have been minimized or mitigated by low water temperature and the very small particle size of material in suspension. Newcombe's comments are also applicable to the other potential effects of suspended sediment and turbidity that could have occurred.

Biochemistry

The use of biochemical analyses by which to ascertain the nutritional state of fish and assess the effect of stressful circumstances (e.g. temperature, sediment) has received attention in recent years. Such analyses were used in this study to complement, and provide different measures of the health

[1] These data have not been subjected to statistical analysis at the time of writing. It is expected that there would not be a significant difference between the growth of control fish and those exposed to 100 mg·L^{-1} suspended sediment.

of the coho salmon in the experiments that might not be determined through traditional techniques. The rationale for the use of these measures is provided below.

Measurement of biological macromolecules has been hypothesized to be a more sensitive indicator of overall fish health than traditional morphometric parameters such as length, weight and condition factor (Buckley and Lough, 1987; Robinson and Ware, 1988; Hakanson et al., 1994; Lochman et al., 1994; Chicharo et al., 1998; Beckman et al., 2000).

Biological macromolecules, specifically lipids, nucleic acids and proteins, have important, but different biological roles. In particular, energy allocation strategies in larval and juvenile fishes are a critical determinant of their survival (Post and Parkinson, 2001).

Lipid storage and dynamics play critical roles in the health of fishes by influencing energy allocation, responses to environmental stressors, overwintering survival (Cunjak, 1988; Sogard and Olla, 2000), migration and reproductive fitness (Justus and Fox, 1994; Silverstein et al., 1998). In particular, energy allocation in juvenile fishes is a critical determinant of their survival. Total body lipid content measured in a solvent extract is a commonly used index of long-term growth potential and survival of fishes.

When assessing fish health, total body lipid content is a cruder measure to use because it includes all lipids (e.g. cell membranes and other structural lipids) in addition to energy storage lipids like triglycerides. However, triglycerides, being the major energy storage molecule in fishes, may have more ecological and physiological relevance as a measure of long-term growth potential, and survival, particularly in juvenile fishes (Hakanson et al., 1994; Lochman et al., 1995). Triglycerides represent more of a measure of energy storage in fish than growth. If there are sufficient food resources available to allocate to growth and maintenance, then any remaining food energy may be allocated to energy storage. High levels of triglycerides in fish are beneficial as they represent a bank of energy that is available for future withdrawals.

Among the biochemical indices, the ratio of ribonucleic acid (RNA) to deoxyribonucleic acid (DNA) has been proven as a useful and reliable indicator of nutritional condition (Buckley, 1979) and growth of larval and juvenile fishes (Ferguson and Danzmann, 1990). Tissue nucleic acid concentrations have been used as a sensitive measure to infer recent short-term (days to weeks) growth of fish larvae and juveniles and the RNA:DNA ratio has been shown to be a measure of protein synthesis (Imsland et al. 2002; Ferguson and Danzmann, 1990).

Total tissue protein content provides a measure of longer-term growth (weeks to months), and is also a measure of energy storage since proteins can be utilized as energy sources, particularly under conditions of severe stress (Mathers et al., 1993; Bulow, 1970).

The use of the RNA:DNA ratio is based on the premise that although the quantity of DNA per cell is believed to be normally stable, the quantity of RNA, primarily associated with ribosomes, is directly proportional to the rate of protein synthesis (Gwak and Tanaka, 2001). Since larval growth is dependant upon protein synthesis, the RNA:DNA ratio has been shown to be highly sensitive to feeding levels, and can be used as an index of fish growth (Gwak and Tanaka, 2001). The RNA:DNA ratio has been used to investigate the effects of salinity on growth (Imsland et al.,

2002), the effect of age and temperature on growth (Goolish et al., 1984; Mathers et al., 1993), and the effect of sublethal toxicant exposure on growth (Barron and Adelman, 1984).

The results of the biochemical analyses that were undertaken on samples of fish collected at specific time intervals for the troughs throughout the 6.5 month exposure period were expected to reveal changes in the nutritional state and growth of the fish relative to the conditions they experienced.

Triglyceride and Protein: It was anticipated that the fish fed the low yet augmented food regime may have higher levels of the triglyceride energy storage compounds, and protein, but that each may be affected if stressful events occur (such as exposure to elevated levels of suspended sediment and turbidity that may elevate metabolism and deplete such stores). However, statistical analyses determined that there was no significant difference between treatment groups of fish on any of the sampling dates. There were significant reductions in the triglyceride content of the fish from each treatment group over time implying the progressive depletion of energy reserves, but the final and lower levels were not significantly different than initial values. This result was probably associated with the increased food ration and feeding regime towards the end of experimentation and the corresponding metabolic response of the fish.

Similarly, protein levels were not significant between treatment groups on sampling dates and over time. Minimum values were recorded in the mid winter period (February, 2002).

These determinations of triglyceride and protein concentration reveal that the coho salmon in the experiments were not receiving sufficient food to compensate for the slight growth that occurred during the low-temperature period of the experiment or in the spring when rapid growth occurred under rising temperature and feeding regimes/rations. Had the metabolic requirements of growth and maintenance been satisfied through food ration, any remaining energy would have been allocated to storage and reflected in the maintenance or increase in triglycerides and tissue protein.

For reasons already stated it is not expected that elevations of suspended sediment and turbidity would have resulted in increased metabolic demands of the fish in the hatchery. The levels experienced were very low and less than those that have been determined to cause adverse sublethal effects or lead to decreased survival (i.e. reduced growth rate) upon chronic exposure.

The reduction in the BCI of fish in the troughs, the generally higher values of those fish on the augmented food regime, and the increases in response to more food also support the contention that food supply and not suspended sediment and turbidity were more influential variables affecting the nutritional state and growth of the fish.

DNA and RNA: The DNA level for fish fed the augmented ration of food was significantly higher than that of the fish on the normal regime on the first sampling occasion, but hereafter there was no difference. DNA levels decreased in both groups over time.

The RNA values were not significantly different between treatments over the sampling period. However, significant decreases in RNA occurred for those fish fed the normal regime followed by an increase in the spring in response to rapid growth and more food. For those fish on the augmented food regime the results were more variable but nevertheless reflected the importance of

food and growth in the spring. In April when food rations and feeding frequency were increased for fish in both treatment groups, the RNA concentration increased rapidly.

In accordance with these changes the ratio of RNA:DNA also increased rapidly in April, 2002. Changes in the RNA:DNA ratios were attributable not only to changes in the RNA concentration or the DNA concentration. RNA concentrations remained almost constant and were not obviously different between fish fed the normal food regime and fish fed on the augmented food regime. However, both the DNA concentration and triglyceride concentration generally decreased concomitantly over the 5 sampling dates.

The values of the ratio of RNA:DNA determined in this study are not dissimilar to those recorded by Bulow (1970) for golden shiners (*Notemigonus crysoleucas*) fed at 6% body weight for 15 d. But starvation in these fish resulted in the mean ratios of 1.36 - 1.66, levels quite different and lower than those determined over winter for coho salmon. The levels determined in coho salmon were also similar to those determined by Mathers et al. (1993) for recently hatched rainbow trout, and the ratio of RNA:DNA of starved fish was similar to the lowest values determined for coho salmon in this experiment (notwithstanding different species and experimental conditions etc.).

The rapid response of RNA:DNA ratio to increased food supply was demonstrated by Bulow (1970) who determined that such changes were primarily related to changes in RNA. A similar response to increased food rations was determined for the coho salmon in the spring 2002. Gwak and Tanaka (2001) determined the opposite response under conditions of starvation when the RNA content of Japanese flounder (*Paralichthys olivaceus*) larvae were determined to decrease "drastically".

Deductions from Results: Collectively, the results of the biochemical analyses revealed the varying nutritional state of the fish held in the troughs during this experiment. The general response of the fish to food, or relative lack thereof, was reflected in each of the indices, and it would have been expected that stressful events leading to increased metabolic demands during the winter could have induced more significant changes in the biochemical measures. In accordance with the expectations of Lemly (1996) such increased metabolic demands at times when fish are typically consuming little or no food in winter has been shown to decrease the survival of juvenile fish.

The response of the measured biochemical variables to changes in food and feeding in the experimental fish implies that the fish were not, in general, fed a ration that would enable the fish to accommodate additional metabolic demands. The protected environment of the hatchery therefore reduced the dependence of the fish on a more available food supply, as would be required in the wild. Whole body lipids, whole body triacylglycerols, muscle RNA:DNA ratios and muscle proteins in wild juvenile chinook salmon (*Oncorhynchus tshawytscha*) collected in different seasons over two years from the Bridge and Yalakom Rivers in British Columbia revealed significant seasonal differences in these parameters (D. Janz University of Saskatchewan, SK; unpublished data).

Interestingly the apparent general correlation between growth, condition, and biochemical indices reveal a similar pattern of response by the fish to food and growth (and decreased metabolism during exposure to low water temperature in winter). While we did not specifically determine that changes in suspended sediment or turbidity in the incoming water to the hatchery

influenced the growth of the fish, statistical analyses that revealed the most related variables, predictions of SIE, and current knowledge, lead to the deduction that effects were improbable. The highest and most variation in suspended sediment and turbidity occurred coincidentally with declining temperature and it was during this time that the biochemical indices revealed that the fish were generally in their most nutritionally stressed state. Counter to this observation are the analyses that revealed that temperature and suspended sediment (turbidity) were not correlated, and that growth rate of the coho salmon was not associated with turbidity (suspended sediment) but with food ration and temperature. Thus it is concluded that the changes in the biochemical indices that were measured in the experimental fish were most likely not as a consequence of exposure to low levels of suspended sediment and the associated turbidity.

Behaviour

The natural environment in which fish live is dynamic and fraught with challenges that, if met, will facilitate their survival. While the maintenance of fish health and performance are critical to the meeting of such challenges, the inherent behaviour of fish is intimately associated with these factors and their survival. Innate behaviour has ensured the survival of individual fish, and hence populations over time, and is, presumably, adaptive.

Examinations of the behavioural responses of fish provide data relevant to an assessment of aquatic variables; opinion reinforced by Schreck et al. (1997) who state that behavioural measures may be readily interpreted within an ecological context, thereby increasing the efficacy of extrapolating laboratory results to the field. However, it is the integration of behavioural responses by fish to the multiple cues in their dynamic environment that requires resolution, if a meaningful understanding of their adaptive capacity and response(s) to various environmental conditions is to be attained.

In the context of the studies at the Capilano Salmon Hatchery, we considered the appropriateness of tests to reveal whether exposure to the conditions experienced over the winter were stressful to the fish and thereby would evoke a change in their behaviour: a quantitative change that would be detrimental to the fish in the wild.

Behavioural tests have generally proven to be more relevant to an assessment of the consequences of stress (Mesa, 1994) than some of the typical biochemical indices (e.g. corticosteroids) because the behaviours that have a high survival value tend to recover faster to baseline levels than do some biochemical indicators (Olla et al., 1992; Mesa, 1994; Schreck, 1981; Schreck et al., 1997), although this is not always so (Olla et al., 1995). While the physiological effects of multiple stressors have been shown to be cumulative (Olla et al., 1995), and relative to the effects of a single stressor, exposure to multiple stressors would result in a longer period to recover anti-predator evasion behaviours.

A whole organism test that had an end point that was not only relevant to the survival of individual fish but which was also was ecologically meaningful was chosen. A fish that is less fit, and therefore is less able to effectively compete for food and avoid predators is, potentially, likely to be selectively preyed upon (Bams, 1967). For example, the impaired escape response behaviour of juvenile chinook salmon to seek cover when alarmed has been successfully used to reveal the effects of exposure to stressful conditions such as handling (Sigismondi and Weber, 1988);

contaminants (Kruzynski et al., 1994); sediment (I.K. Birtwell and J.S. Korstrom, Fisheries and Oceans Canada, West Vancouver Laboratory, West Vancouver, BC, unpublished data). Similarly, the escape response of juvenile ("subyearling") coho salmon to cover was demonstrated by Bugert and Bjornn (1991). They determined that these fish sought cover in artificial streams in the absence of predators, and in response to brook trout and a simulated kingfisher the coho salmon were seen to "flee and seek cover". However, once the threat of the predator was removed the fish returned to their feeding stations within 1 min. Clearly, a fish that is less able to flee for cover is likely to be selectively preyed upon than a fish that is not so impaired.

Cover Response: The response of fish to seek cover was examined at discrete time intervals during the experiment. We anticipated that if there was either an event that was acutely stressful to the fish and/or stress induced through the cumulative and chronic 6.5 month exposure to, for example, elevated levels of suspended sediment and turbidity, the behavioural response of the coho salmon to seek cover may have been compromised.

The results of the experiments that sequentially assessed the response of juvenile coho salmon to cover at the Capilano Salmon Hatchery, revealed that in all trials the fish generally and consistently moved rapidly to cover (< 3 s) and there was no result that implied an impairment of this behaviour due to prior exposure to highly stressful conditions.

We concluded that the conditions experienced by the juvenile coho salmon during winter 2001/2002 did not impair their ability to rapidly seek cover. That said, however, fishes from one trough (#3) sought cover faster than did the rest. The fish from trough #3 (and #4) were not fed the augmented food regime, and relative to those fish from troughs #1 and #2 they were significantly smaller yet took less time to reach cover. The 0.6 s time interval between mean times to cover between treatments represents a 60 cm difference for a 100 mm fish swimming at 6 $bl \cdot s^{-1}$.

The swim speed of fish from trough #3 was the fastest of all groups tested even when normalized for body length, and just exceeded the upper sustained swim speed of juvenile coho salmon (approximately 5 $bl \cdot s^{-1}$; Pukett and Dill, 1984) recorded under laboratory conditions. An explanation for this rapid cover seeking response by fish from trough #3, is not easy to obtain. All fish in the various treatment groups were subjected to the same conditions within the cover test tank, and although temperature varied during the course of the 6 trials, it was determined statistically to not be a factor to consider. This latter finding supports the work of Brett (1964, 1965, and 1967) who reported that burst speed is primarily and anaerobic activity that is independent of temperature. The augmented food regime given to fish in troughs #1 and #2 resulted in a larger mean mass and length at a given time relative to fish from troughs #3 and #4. This larger size may have influenced the orientation of the fish entering the cover response tank and initial response to cover. A significantly lower number of fish that received augmented food regimes entered the test tank head first, and there was a trend of decreasing numbers of fish entering head first from the first to the last trial (perhaps a reflection of their increasing size influencing orientation and subsequent swim speed); such a trend was not as evident for the fish from troughs #3 and #4. Paralleling this trend was the change in Body Condition Index (BCI) which revealed the increased condition of fish fed the augmented food regime with proximity to the end of the experiment. However, in that the BCI for all groups of fish lay above but close to unity, the biological significance of the differences is unclear. Whether size affected the orientation of the fish entering the test tank and in doing influenced the rapidity with which the fish sought cover is not

known but the results imply that there was some influence of, or an artefact of, feeding treatment (which related to size of fish) on the results.

Notwithstanding these findings the ecological relevance may be little, for repeat analysis of the data sets after the removal of those for trough #3 showed no significant difference in the swim speed of fish to cover between treatments, thus implying no significant effect of treatment on the cover response.

The response of the coho salmon to seek cover was rapid, and contrasts with that of chinook salmon that swam slower than control individuals when tested similarly (Sigismondi and Weber, 1988; Birtwell I.K. and J.S Korstrom, Fisheries and Oceans Canada, West Vancouver Laboratory, unpublished data). We have recorded escape burst speeds of chum salmon when chased by predatory rockfish at approximately 19 $bl \cdot s^{-1}$ (Birtwell et al., 2001) and calculated from Sigismondi and Weber (1988) swim speeds of juvenile chinook salmon to seek cover were from approximately 0.5 to 6.1 $bl \cdot s^{-1}$. Pukett and Dill (1984) recorded speeds of juvenile coho salmon feeding on prey to be 9 $bl \cdot s^{-1}$. Juvenile chinook salmon fleeing to cover in trials that compared fish exposed to sediment (SIE level 10.8) with controls swam at a mean (±SD) speed of about 2.68 (± 0.53) $bl \cdot s^{-1}$ and the treated fish at approximately 1.45 (±0.53) $bl \cdot s^{-1}$ (I.K. Birtwell and J.S. Korstrom, Fisheries and Oceans Canada, West Vancouver Laboratory, BC; unpublished data). Thus the swim speeds determined for coho salmon during the cover tests were lower than those that could occur when feeding and when fleeing a predator, but nevertheless generally greater than those determined for sustained swimming by coho salmon, and chinook salmon fleeing to and seeking cover.

Escape from predators has been examined by various researchers in relation to the size of fish and their burst speed, and it is considered by Taylor and McPhail (1985) that the "fast start" response that occurs within a fraction of a second may be closely associated with escape or capture. There is, though, a related importance of speed and manoeuvrability (Howland, 1974). In a study by Taylor and McPhail (1985), the burst speed of juvenile coho salmon was determined to be greatest for the larger individuals and differences of up to 80% in swim performance were recorded within the first 0.03 s. This size-mediated difference in burst speed (approximately 19 $bl \cdot s^{-1}$) was subsequently reflected in the predation of smaller rather than larger individuals of the test population, thus providing a causative factor for the differential mortality of juvenile salmon in the wild and the selection of smaller individuals. Bams (1967) also revealed a correlation between the swim performance of different sizes of sockeye salmon fry and the greater vulnerability to predation of the smaller fish, which swam slower. Brett (1971b) determined how the maximum sustained swim speed is affected by the growth of juvenile salmon and that burst speed, which is virtually independent of temperature, is primarily an anaerobic activity that will incur an oxygen debt and lead to fatigue in the fish (Brett, 1964, 1965, and 1967). Repeated bursts of speed to escape predation will lead to fatigue, and it is possible that fish whose swim performance is compromised by stressors will more readily succumb to predation than those individuals not so affected.

Thus in this study, the swim speed of the smaller fish (trough #3) when seeking cover was faster than that of the larger individuals that were fed on the the augmented regime (troughs #1 and #2), and those larger fish also fed the normal regime (trough #4). Accordingly, if survival in the wild is a function of size in relation to swim speed to escape predation and to capture prey, the behavioural

responses of the smaller coho salmon implies the use a compensatory mechanism: through swim speed these fish demonstrated an enhanced ability to reach cover relative to their larger conspecifics.

The application of the model of Newcombe and Jensen (1996) to the data gathered in this study predicted that changes behavioural responses could be evoked due to the exposure of juvenile salmonids to suspended sediment over shorter (e.g. ≤ 504 h intervals) and longer term (e.g. 6.5 months) exposure.

We were not able to determine a behavioural change in relation to exposure to changes in water quality through the use of the cover response test. It is likely that the stress imposed on the fish due to handling, confinement and treatment did not affect the fish to the extent that their fright response was overtly compromised.

In other cover response experiments with the same apparatus juvenile chinook salmon were examined that had previously been exposed to suspended sediment that created an SIE level of 10.8. Significant differences were found between the cover response behaviour of the sediment-exposed treated fish and that of control fish (I.K. Birtwell and J.S. Korstrom, Fisheries and Oceans Canada, West Vancouver Laboratory; unpublished data). In these tests not only was there a number of fish that were immobilized due to the exposure to suspended sediment, the mean swim speed was lower, and they were more disorientated than the control fish.

It is also possible for other behavioural responses to occur in response to exposure to suspended sediment, such as surfacing and avoidance or displacement (McLeay et al., 1987; Servizi and Martens, 1992), but such behaviours were not noticed during the experiments at the Capilano Salmon Hatchery, nor were the elevated levels of suspended sediment that would evoke such behaviours recorded. It was unlikely that any overt abnormal behavioural responses went unnoticed. However, abnormal behaviour may be evoked through exposure to mildly stressful conditions that are not discernible to humans but which can result in detection by other fish and result in increased predation and the selection of "treated" or affected individuals rather than non-treated fish (Birtwell et al., 2001).

Deductions from Results: The highest levels of suspended sediment and turbidity in the waters that entered the hatchery during the winter of 2001, were not at levels that would, in general, evoke significant behavioural responses in the fish (refer to Newcombe and Jensen, 1996; Caux et al., 1997; Birtwell, 1999). But it is possible for very short-term effects on feeding efficiency to have occurred, and also subtle behavioural responses (Berg and Northcote, 1995 - turbidity >20 NTU). However, such transient increases in turbidity and suspended sediment did not result in changes in growth rate, or fright responses, and if they did occur they were considered to be inconsequential the well being of the fish in these experiments.

CONCLUDING COMMENTS

Over the winter 2001/2002 water quality conditions in the Capilano Salmon Hatchery did not adversely affect the experimental populations of juvenile coho salmon over a 6.5-month period. This deduction is based on the results of determinations of the behavioural and biochemical

responses of the fish and the integrating changes in growth rate. There were changes in the responses of the fish to the varying conditions in the water to which they were exposed. These responses were, however, most attributable to seasonal changes in water temperature. The fish were also responsive to the food ration and feeding regime they encountered, and during the winter period the fish grew little. Their health, as reflected by condition index and biochemical analyses, generally responded to food ration and feeding conditions and also to changing and increasing water temperature in springtime.

The lower than anticipated elevation in suspended sediment and turbidity within the hatchery waters occurred over the mid-winter period but the levels attained were relatively low and not expected to overtly harm the fish. There was no obvious reduction in food conversion as had been recorded previously in 1999 by hatchery staff, and the predictions from a model that relates concentration of suspended sediment and the duration of exposure to a severity of ill effect (SIE) support the findings of no effects on growth and survival. There was also no effect on behaviour that could be directly attributable to exposure to suspended sediment and turbidity (most reports of such effects in the literature were manifest at higher suspended sediment concentrations than were determined in this study).

The most obvious factor associated with the growth of the fish, their fright response to seek cover, and their condition and biochemistry was that of food ration and feeding frequency, which was coupled with the controlling factor of temperature.

Fish held in the protected and less challenging environment of the hatchery survived on a minimal ration of food over winter. Some fish displayed marginally reduced and fluctuating condition, and biochemical profiles revealed a similar pattern of response to food and ration.

In the competitive and more challenging environment of the wild the additional metabolic demands on the fish to survive could have led to a more significant reduction in health and fitness given the same food ration and feeding frequency. It is also likely that fish in the Capilano River experienced slightly higher and more variable suspended sediment concentrations and turbidity than was determined in hatchery waters (refer to Appendix 1). Such levels could have evoked behavioural responses but the transient period of elevated levels of suspended sediment and turbidity would have most probably resulted in minor displacement and temporarily decreased feeding efficiency. Because the periods of elevated yet relatively low levels of suspended sediment and turbidity were brief, it is considered unlikely that fish in the wild would have been harmed.

Perhaps by good fortune, but primarily because of good practices and management of the engineering activities that were undertaken on the Cleveland Dam during the winter of 2001/2002, water quality changes in the Capilano River were minimal, and suspended sediment and turbidity less than expected.

The net result of the studies reported herein concludes that there was no obvious effect of the changes in water quality that affected the well being and the growth of fish in the Capilano Salmon Hatchery during the winter 2001/2002.

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Table 1. Mean weekly temperature and dissolved oxygen measurements in waters of Bch 5A at the Capilano Salmon Hatchery between July 2001 and June 2002.

Date	Temperature (° C)	Dissolved Oxygen Concentration (mgL^{-1})
08-Jul	8.2	-
15-Jul	8.5	11.0
22-Jul	8.9	12.0
29-Jul	9.1	10.8
05-Aug	9.5	10.8
12-Aug	10.1	10.9
19-Aug	10.6	10.8
26-Aug	11.8	9.8
02-Sep	13.3	9.9
09-Sep	13.9	8.7
16-Sep	14.7	8.7
23-Sep	15.1	8.2
30-Sep	15.3	8.9
07-Oct	14.2	9.0
14-Oct	13.0	9.2
21-Oct	11.7	9.6
28-Oct	10.0	10.3
04-Nov	8.4	11.2
11-Nov	8.0	11.4
18-Nov	8.1	11.9
25-Nov	7.5	12.5
02-Dec	6.4	-
09-Dec	5.2	12.5
16-Dec	4.3	12.8
23-Dec	2.8	13.6
30-Dec	2.3	13.7
06-Jan	2.8	13.6
13-Jan	3.9	13.9
20-Jan	3.2	13.5
27-Jan	2.7	12.9
03-Feb	1.9	13.4
10-Feb	2.4	13.3
17-Feb	2.5	13.4
24-Feb	3.0	13.3
03-Mar	2.7	13.6

Table 1. Mean weekly temperature and dissolved oxygen measurements in waters of Bch 5A at the Capilano Salmon Hatchery between July 2001 and June 2002.

Date	Temperature (° C)	Dissolved Oxygen Concentration (mgL^{-1})
10-Mar	2.6	13.2
17-Mar	2.7	13.7
24-Mar	2.5	13.4
31-Mar	3.3	13.1
07-Apr	4.0	13.0
14-Apr	4.6	12.5
21-Apr	4.2	12.5
28-Apr	5.5	12.3
05-May	6.5	11.5
12-May	6.8	12.0
19-May	7.4	-
26-May	7.6	11.1
02-Jun	7.6	11.7
09-Jun	8.2	11.7
16-Jun	8.8	12.0
18-Jun	9.1	-
Mean	7.2	11.8
SD	4.0	1.6
Min	1.9	8.2
Max	15.3	13.9
n	51	47

Table 2. Mean weekly temperature and dissolved oxygen measurements in waters of Bch 5B at the Capilano Salmon Hatchery between July 2001 and June 2002.

Date	Temperature (° C)	Dissolved Oxygen Concentration (mgL^{-1})
08-Jul	8.2	-
15-Jul	8.5	11.1
22-Jul	8.9	-
29-Jul	9.1	10.8
05-Aug	9.5	10.8
12-Aug	10.1	10.8
19-Aug	10.6	10.7
26-Aug	11.8	10.0
02-Sep	13.3	10.2
09-Sep	13.9	9.0
16-Sep	14.7	8.9
23-Sep	15.1	8.2
30-Sep	15.3	8.8
07-Oct	14.2	9.0
14-Oct	13.0	9.1
21-Oct	11.7	9.6
28-Oct	10.0	10.3
04-Nov	8.4	11.3
11-Nov	8.0	11.5
18-Nov	8.1	11.9
25-Nov	7.5	12.0
02-Dec	6.4	-
09-Dec	5.2	12.9
16-Dec	4.3	12.7
23-Dec	2.8	13.7
30-Dec	2.3	13.8
06-Jan	2.8	13.6
13-Jan	3.9	13.8
20-Jan	3.2	13.6
27-Jan	2.7	13.0
03-Feb	1.9	13.3
10-Feb	2.4	13.3
17-Feb	2.5	13.5
24-Feb	3.0	13.3

Table 2. Mean weekly temperature and dissolved oxygen measurements in waters of Bch 5B at the Capilano Salmon Hatchery between July 2001 and June 2002.

Date	Temperature (° C)	Dissolved Oxygen Concentration (mgL^{-1})
03-Mar	2.7	13.6
10-Mar	2.6	13.3
17-Mar	2.7	13.6
24-Mar	2.5	13.3
31-Mar	3.3	13.1
07-Apr	4.0	13.0
14-Apr	4.6	12.5
21-Apr	4.2	12.4
28-Apr	5.5	12.4
05-May	6.5	11.4
12-May	6.8	12.1
19-May	7.4	-
26-May	7.6	11.2
28-May	7.6	-
Mean	7.1	11.8
SD	4.1	1.7
Min	1.9	8.2
Max	15.3	13.8
n	48	43

Table 3. Sampling schedule for experiments conducted at Capilano Salmon Hatchery between November 21, 2001 and May 30, 2002.

Parameter Sampled	Measurement Frequency/ Date
Dissolved Oxygen Saturation (mgL^{-1})	Daily (Monday-Friday)
Dissolved Oxygen Saturation (%)	Daily (Monday-Friday)
Water Temperature (° C) (Manual)	Daily (Monday-Friday)
Water Temperature (° C) (Logged)	Hourly
Turbidity (NTU) (Manual)	Daily (Monday-Friday)
Turbidity (NTU) (Logged)	Hourly
pH	Weekly (Thursdays)
Total Gas Pressure (%)	Nov 20, 2001, Dec 4, 2001, Dec 19, 2001, Feb 5, 2002, Mar 19, 2002, April 23, 2002, May 23, 2002
Total Suspended Solids (mgL^{-1})	Daily (Monday-Friday)
Length and Mass Determination	Nov 21, 22 2001; Dec 12, 13 2001; Jan 2, 3 2002; Jan 23, 24 2002; Feb 13, 14 2002; Mar 6, 7 2002; Mar 27, 28 2002; Apr 17, 18 2002; May 8, 9 2002; May 29, 30 2002
Biochemical Analysis	Nov 27, 2001, Dec 18, 2001, Jan 8, 2002, Jan 29, 2002, Feb 19, 2002, Mar 12, 2002, Apr 2, 2002, Apr 23, 2002, May 14, 2002, Jun 4, 2002
Cover Response Trials	Jan 31, 2002, Feb 21, 2002, Mar 14, 2002, Apr 4, 2002, Apr 25, 2002, May 16, 2002
Particle Size Analysis	Nov 7, 2001, Feb 4, 2002
Invertebrate Population	Feb 5, 2002, May 14, 2002
Light Intensity ($\mu Em^{2}s^{-1}$)	Nov 16, 2001, Feb 21, 2002, May 14, 2002

Table 4. Mean and standard deviation of daily water quality determinations from November 21, 2001 to May 30, 2002 in each experimental trough at the Capilano Salmon Hatchery.

		Dissolved Oxygen Concentration (mgL^{-1})		Dissolved Oxygen % Air Saturation		Temperature (° C)		pH		Turbidity (NTU)		Total Gas Pressure (%)	
Food Regime	**Trough**	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Augmented	1	12.4	0.5	98.4	2.6	4.0	1.8	6.5	0.4	5.75	4.01	99.7	1.2
	2	12.4	0.5	98.1	2.6	4.0	1.8	6.5	0.4	5.81	4.13	99.7	1.2
Normal	3	12.4	0.5	98.0	2.9	4.0	1.8	6.5	0.4	5.76	4.06	99.7	1.2
	4	12.4	0.5	98.6	2.1	4.0	1.8	6.5	0.4	5.78	4.12	99.7	1.2

Table 5. Mean and standard deviation of water quality parameters per 21-d sampling period, measured daily in all experimental troughs at the Capilano Salmon Hatchery, 2001-2002.

	Dissolved Oxygen (ppm)		Oxygen Saturation (%)		Temperature (° C)		pH		Turbidity (NTU)	
Start Date	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
22-Nov-01	11.7	0.6	94.28	3.5	5.7	1.04	6.3	0.3	5.13	1.85
13-Dec-01	12.7	0.2	98.0	1.4	2.6	0.6	6.3	0.2	11.32	4.75
03-Jan-02	12.5	0.1	98.1	0.7	3.1	0.5	6.3	0.1	11.75	3.54
24-Jan-02	12.7	0.2	97.7	1.5	2.0	0.3	6.7	0.2	5.28	1.76
14-Feb-02	12.8	0.1	98.7	1.0	2.6	0.2	6.8	0.1	5.50	2.72
07-Mar-02	12.8	0.1	99.2	0.8	2.5	0.3	6.6	0.4	4.84	1.20
28-Mar-02	12.5	0.2	99.7	1.0	3.8	0.5	6.7	0.2	3.31	1.86
18-Apr-02	12.3	0.2	100.3	0.7	5.5	0.9	6.8	0.1	3.52	0.95
09-May-02	12.1	0.1	100.0	0.9	6.6	0.3	6.8	0.4	1.68	0.41

Table 6. Monthly mean and standard deviation of temperature data logged hourly in each experimental trough at the Capilano Salmon Hatchery, 2001-2002.

	Temperature (°C)																	
Date	**Nov-01**		**Dec-01**		**Jan-02**		**Feb-02**		**Mar-02**		**Apr-02**		**May-02**		**Jun-02**		**Overall**	
Tank	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	7.23	0.48	3.69	1.27	3.04	0.63	2.58	0.32	2.84	0.26	4.60	0.78	6.83	0.49	7.71	0.33	4.28	1.85
2	7.24	0.48	3.70	1.28	3.05	0.62	2.57	0.32	2.84	0.27	4.60	0.78	6.83	0.49	7.72	0.33	4.28	1.85
3	7.25	0.48	3.70	1.27	3.04	0.65	2.58	0.32	2.84	0.26	4.59	0.78	6.84	0.49	7.72	0.33	4.28	1.85
4	7.26	0.48	3.71	1.27	3.06	0.64	2.59	0.31	2.85	0.27	4.61	0.79	6.85	0.49	7.73	0.33	4.29	1.85

Table 7. Mean and standard deviation of water quality parameters determined in each experimental tank between November 21, 2001 and May 29, 2002 at the Capilano Salmon Hatchery.

	Dissolved Oxygen				Temperature		pH		Turbidity		Total Gas	
	Concentration (mgL^{-1})		% Air Saturation		(°C)				(NTU)		Pressure (%)	
Tank	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	12.4	0.3	98.3	1.2	3.9	1.7	6.5	0.3	5.70	4.02	99.8	1.0
2	12.4	0.3	98.3	1.2	3.9	1.7	6.5	0.3	5.66	3.97	99.8	1.0
3	12.4	0.3	98.3	1.2	3.9	1.7	6.5	0.3	5.69	4.07	99.7	1.0
4	12.4	0.3	98.3	1.2	3.9	1.7	6.5	0.3	5.68	3.98	99.8	1.0
5	12.4	0.3	98.3	1.2	3.9	1.7	6.5	0.3	5.67	3.99	99.7	1.0
6	12.4	0.3	98.3	1.2	3.9	1.7	6.5	0.3	5.72	4.12	99.8	1.0
7	12.4	0.3	98.4	1.2	3.9	1.7	6.5	0.3	5.74	4.04	99.8	1.1
8	12.4	0.3	98.3	1.2	3.9	1.7	6.5	0.3	5.72	4.00	99.8	1.0
9	12.4	0.3	98.4	1.2	3.9	1.7	6.5	0.3	5.69	4.00	99.7	1.0
10	12.4	0.3	98.3	1.3	3.9	1.7	6.5	0.3	5.73	4.02	99.8	1.0

Table 8. Mean and standard deviation of water quality parameters determined in all experimental tanks at the Capilano Salmon Hatchery by 21-d sampling period, 2001-2002.

	Dissolved Oxygen (mgL^{-1})		**Dissolved Oxygen (%)**		**Temperature (° C)**		**pH**		**Turbidity (NTU)**	
Start Date	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
21-Nov	12.1	0.2	97.8	1.0	5.9	1.0	6.3	0.2	5.54	2.36
12-Dec	12.6	0.2	97.4	1.1	2.7	0.7	6.3	0.2	10.81	5.37
03-Jan	12.5	0.1	98.2	0.8	3.2	0.4	6.2	0.1	11.60	3.58
23-Jan	12.6	0.2	97.0	1.3	2.0	0.3	6.5	0.1	5.48	1.54
13-Feb	12.8	0.1	98.6	0.9	2.5	0.2	6.8	0.2	5.15	2.77
06-Mar	12.7	0.1	98.3	0.7	2.5	0.2	6.5	0.3	4.97	1.15
28-Mar	12.5	0.2	99.1	0.9	3.8	0.6	6.7	0.2	3.05	1.74
17-Apr	12.2	0.2	99.7	0.8	5.3	1.1	6.8	0.0	3.69	1.07
08-May	12.0	0.1	98.9	0.7	6.6	0.4	6.8	0.3	1.73	0.41

Table 9. Monthly mean and standard deviation of temperature data logged hourly in each experimental tank at the Capilano Salmon Hatchery, 2001-2002.

	Temperature (°C)															
Date	**Nov-01**		**Dec-01**		**Jan-02**		**Feb-02**		**Mar-02**		**Apr-02**		**May-02**		**Overall**	
Tank	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	6.90	0.31	3.67	1.26	3.01	0.62	2.54	0.32	2.81	0.27	4.56	0.77	6.79	0.49	4.03	1.69
2	6.93	0.30	3.68	1.26	3.02	0.64	2.56	0.31	2.82	0.26	4.58	0.78	6.81	0.48	4.05	1.70
3	6.98	0.31	3.76	1.26	3.10	0.63	2.63	0.32	2.90	0.27	4.65	0.77	6.88	0.48	4.12	1.69
4	6.92	0.30	3.69	1.26	3.03	0.63	2.57	0.31	2.83	0.27	4.59	0.78	6.81	0.49	4.05	1.69
5	6.94	0.31	3.70	1.26	3.04	0.63	2.58	0.31	2.84	0.27	4.60	0.78	6.82	0.49	4.07	1.69
6	6.91	0.30	3.67	1.27	3.00	0.64	2.54	0.31	2.80	0.27	4.57	0.79	6.80	0.48	4.03	1.70
7	6.89	0.31	3.67	1.28	3.00	0.63	2.54	0.32	2.80	0.27	4.56	0.78	6.79	0.49	4.03	1.70
8	6.93	0.31	3.69	1.29	3.03	0.63	2.56	0.32	2.82	0.27	4.58	0.79	6.82	0.49	4.05	1.70
9	6.90	0.31	3.66	1.27	3.01	0.63	2.54	0.32	2.80	0.27	4.56	0.79	6.80	0.49	4.03	1.70
10	6.98	0.31	3.65	1.33	2.93	0.63	2.46	0.32	2.73	0.27	4.50	0.78	6.73	0.49	3.98	1.72

Table 10. Monthly mean, minimum, maximum and standard deviation of turbidity logged hourly in water supplied to Basement Chamber 3 at the Capilano Salmon Hatchery, 2001-2002.

	Turbidity								
Month	**Nov-01**	**Dec-01**	**Jan-02**	**Feb-02**	**Mar-02**	**Apr-02**	**May-02**	**Jun-02**	**Overall**
Mean	7.56	8.93	10.20*	6.55**	5.42	4.28	2.11	1.94	6.10
Min	4.75	2.81	5.25	3.81	2.81	1.81	1.31	1.81	1.31
Max	12.63	42.69	36.75	24.44	8.69	19.06	3.81	7.25	42.69
Std Dev	2.05	5.70	3.69	2.88	1.51	2.41	0.58	0.58	4.13

* 103 h removed from Jan 9-14, 2002.

** Meter in disagreement with manual measurements by ~2 NTU from Feb 11-25, though no meter malfunction evident

Table 11. Determinations of the turbidity and suspended sediment in waters from the Capilano River as well as in the tanks and troughs at the Capilano Salmon Hatchery, 2001-2002.

	Capilano River		Tanks		Troughs	
	Turbidity (NTU)	Suspended Sediment (mgL^{-1})	Turbidity (NTU)	Suspended Sediment (mgL^{-1})	Turbidity (NTU)	Suspended Sediment (mgL^{-1})
Mean	8.61	4.08	5.80	3.03	5.78	2.73
SD	7.43	6.77	4.01	3.78	4.18	3.90
Min	1.54	0.00	1.12	0.00	1.13	0.00
Max	42.60	43.00	19.70	17.50	17.90	18.50
n	83	83	263	263	146	146

Table 12. Particle size analysis of suspended sediment from samples of water collected from the Basement Chamber 3 supply line, once during a period of increased turbidity and again during a period of low turbidity, 2002.

		Particle Size Range				
		>0.020 (mm)	<0.020 - >0.005 (mm)	<0.005 - >0.0025 (mm)	<0.0025 - >0.00047 (mm)	Total
Date	Turbidity (NTU)	Mass of Solids (mgL^{-1})				
30-Oct-01	16.30	3.8	9.7	6.7	0.7	20.9
		18.3%	**46.4%**	**32.1%**	**3.2%**	
05-Feb-02	5.39	2.2	3.1	2.1	0.4	7.8
		28.2%	**39.7%**	**26.9%**	**5.1%**	

Table 13. Macroinvertebrate (>200μm) counts in 57,600 L of water collected during the winter and spring from the Basement Chamber 3 supply line at the Capilano Salmon Hatchery, 2002.

Taxa	Life Stage	Date	
		#####	14-May
Rotifera	-	0	1
Ostracoda	Adult	1	1
Cladocera	Adult	0	2
Copepoda	Adult	46	762
Diptera	Larvae	0	15
Diptera	Pupae	0	2
Ephemeroptera	Nymph	1	4
Eggs	-	1	0

Table 14. Light Intensity measured in experimental tanks at the Capilano Salmon Hatchery, Nov 16, 2001.

	Light Intensity ($\mu Es^{-1}m^{-2}$)		
	Uncovered	Covered	
Tank		Dark Side	Light Side
1	2.12	0.55	1.20
2	2.27	0.55	1.33
3	2.20	0.54	1.32
4	1.99	0.52	1.13
5	1.78	0.52	1.03
6	1.74	0.54	1.13
7	1.94	0.52	1.25
8	2.03	0.54	1.18
9	2.00	0.50	1.29
10	1.68	0.51	1.02
Mean	1.98	0.53	1.19
SD	0.20	0.02	0.11
Min	1.68	0.50	1.02
Max	2.27	0.55	1.33

Note: Covered indicates 50% occluded lid creating dark and light sides.

Table 15. Light intensity measured in experimental troughs at the Capilano Salmon Hatchery, 2002.

		Light Intensity ($\mu Es^{-1}m^{-2}$) Location			
Trough	**Date**	**Under Cover**	**Mid-Trough**	**Inlet End**	**In Cage**
1	21-Feb	0.45*	0.67*	-	0.34*
	14-May	0.70	1.90	2.20	-
2	21-Feb	0.45*	0.77*	-	0.32*
	14-May	0.70	1.80	2.00	-
3	21-Feb	0.51	1.45	-	0.37
	14-May	0.60	1.70	1.60	-
4	21-Feb	0.57	1.26	-	0.38
	14-May	0.70	1.90	2.00	-

* fluorescent lights above tank were burnt out when determinations were taken

Table 16. Length (mm), mass (g) and Body Condition Index of juvenile coho sampled every 21-d, in experimental troughs at the Capilano Salmon Hatchery, n=50

	Length (mm)								Mass (g)								Body Condition Index							
Feed Regime	Augmented				Normal				Augmented				Normal				Augmented				Normal			
Trough	1		2		3		4		1		2		3		4		1		2		3		4	
Date	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
22-Nov	97.4	5.6	97.5	5.9	96.9	5.0	97.6	5.3	10.35	1.97	10.29	1.98	10.23	1.56	10.39	1.85	1.11	0.04	1.10	0.04	1.12	0.06	1.11	0.05
13-Dec	97.9	5.6	98.8	6.1	97.4	5.7	96.6	5.5	10.28	1.81	10.64	2.10	10.01	1.77	9.80	1.75	1.08	0.05	1.09	0.05	1.07	0.04	1.08	0.04
03-Jan	99.0	6.2	97.8	6.9	98.1	6.0	98.0	6.5	10.31	1.92	10.05	2.33	10.09	1.99	10.05	2.17	1.05	0.06	1.06	0.06	1.05	0.04	1.05	0.07
24-Jan	98.1	5.7	98.5	5.2	97.4	5.2	97.6	5.8	10.02	1.91	10.43	1.85	9.91	1.79	10.05	1.83	1.05	0.06	1.08	0.07	1.06	0.07	1.07	0.05
14-Feb	99.0	5.4	98.4	5.3	98.0	6.2	98.2	5.8	10.24	1.57	10.18	1.57	9.76	1.92	10.10	1.87	1.05	0.06	1.06	0.06	1.02	0.05	1.05	0.04
07-Mar	100.7	4.9	100.2	5.4	98.8	6.2	99.5	5.1	11.27	1.85	11.10	1.94	10.27	2.05	10.56	1.69	1.09	0.08	1.09	0.06	1.05	0.06	1.06	0.07
28-Mar	101.1	5.2	103.0	5.9	98.7	4.7	98.6	5.9	11.59	1.95	12.32	2.42	10.10	1.50	10.24	1.99	1.11	0.06	1.11	0.08	1.05	0.05	1.06	0.06
18-Apr	105.0	5.8	103.3	6.0	99.3	6.2	99.0	6.7	13.23	2.52	12.45	2.20	10.15	2.14	10.11	2.43	1.13	0.06	1.12	0.07	1.02	0.06	1.02	0.07
09-May	109.7	7.1	110.4	6.6	102.2	6.3	103.0	7.7	14.57	2.91	14.89	2.91	12.33	2.42	12.46	2.62	1.09	0.07	1.09	0.07	1.14	0.08	1.13	0.06
30-May	117.3	7.7	118.3	6.9	111.5	6.2	112.0	7.5	17.76	3.69	18.07	3.44	14.89	2.54	14.93	3.16	1.09	0.06	1.08	0.07	1.07	0.05	1.05	0.06

Table 17. Length (mm) of juvenile coho salmon fed a normal regime in experimental tanks, determined every 21-d, n=20 per tank, at the Capilano Salmon Hatchery, 2001-2002.

	Length (mm)																			
Tank	**21-Nov**		**12-Dec**		**02-Jan**		**23-Jan**		**13-Feb**		**06-Mar**		**27-Mar**		**17-Apr**		**08-May**		**29-May**	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	98.4	4.5	99.7	4.5	99.9	4.5	100.3	4.5	100.4	4.4	100.9	4.5	101.5	4.5	102.2	4.9	104.7	5.4	111.1	6.0
2	98.5	3.4	100.4	3.3	100.5	3.4	100.9	3.4	101.1	3.4	101.3	3.5	101.8	3.7	102.2	3.7	105.6	4.7	111.7	6.2
3	98.7	4.0	99.8	4.0	100.1	3.9	100.5	3.9	100.7	4.0	101.0	4.0	101.4	4.2	102.1	4.6	105.0	5.7	110.7	6.3
4	98.4	4.0	99.4	3.7	99.8	3.8	100.0	3.6	100.3	3.7	100.7	3.6	101.0	3.7	101.7	4.0	104.5	4.4	109.9	5.6
5	98.9	4.0	100.2	4.1	100.6	4.0	100.7	4.0	101.2	3.7	101.6	3.4	101.9	3.2	102.4	3.3	105.0	3.4	111.1	4.4
6	99.0	4.2	100.4	4.2	100.8	4.1	100.9	4.1	101.2	4.0	101.3	4.0	102.1	4.5	102.5	4.6	104.9	4.9	110.3	6.3
7	97.2	4.5	98.4	4.6	98.7	4.5	98.9	4.5	99.2	4.5	99.5	4.5	100.1	4.5	100.7	4.6	104.3	5.7	110.6	7.0
8	97.2	4.0	98.3	4.1	98.6	4.2	99.0	4.2	99.3	4.2	99.6	4.0	100.1	4.1	100.7	4.2	104.0	4.5	110.5	4.9
9	97.5	4.7	98.7	4.8	99.0	4.7	99.3	4.8	99.5	4.8	99.7	4.7	100.2	4.7	100.9	4.7	103.4	4.8	108.2	4.6
10	98.4	3.6	99.7	3.5	99.9	3.6	100.3	3.9	100.6	3.8	100.9	3.8	101.2	3.8	102.0	4.2	105.1	4.4	111.2	4.8

Table 18. Mass (g) of juvenile coho salmon fed a normal regime in experimental tanks, determined every 21-d, n=20 per tank, at the Capilano Salmon Hatchery, 2001-2002.

	Mass (g)																			
Tank	**21-Nov**		**12-Dec**		**02-Jan**		**23-Jan**		**13-Feb**		**06-Mar**		**27-Mar**		**17-Apr**		**08-May**		**29-May**	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	11.63	1.47	11.07	1.40	11.02	1.37	11.04	1.38	10.95	1.38	11.14	1.49	11.20	1.61	11.52	1.86	12.62	2.03	15.47	2.61
2	11.48	1.28	11.15	1.24	11.00	1.10	10.94	1.27	10.91	1.29	11.02	1.38	11.23	1.45	11.37	1.62	12.72	2.25	15.51	2.79
3	11.46	1.58	10.93	1.48	10.78	1.45	10.82	1.49	10.75	1.51	11.04	1.63	11.11	1.73	11.31	1.88	12.49	2.33	14.65	2.59
4	11.48	1.39	10.90	1.33	10.78	1.31	10.85	1.36	10.75	1.39	10.92	1.50	10.95	1.60	11.20	1.75	12.42	2.02	14.45	3.13
5	11.89	1.63	11.22	1.46	11.06	1.37	11.15	1.19	11.11	1.18	11.23	1.05	11.33	1.06	11.55	1.11	12.67	1.49	15.17	2.22
6	11.75	1.58	11.06	1.47	10.92	1.36	11.03	1.35	10.98	1.37	11.14	1.45	11.26	1.51	11.38	1.68	12.50	1.96	14.93	2.68
7	11.19	1.70	10.50	1.53	10.37	1.48	10.44	1.47	10.44	1.47	10.62	1.52	10.74	1.55	10.92	1.71	12.77	2.32	14.91	2.80
8	11.08	1.63	10.52	1.57	10.45	1.51	10.57	1.41	10.54	1.39	10.74	1.51	10.81	1.54	11.18	1.68	12.59	1.71	15.17	2.12
9	11.24	1.87	10.59	1.67	10.55	1.75	10.56	1.69	10.47	1.70	10.69	1.78	10.70	1.70	10.97	1.77	12.13	2.21	13.89	2.46
10	11.43	1.55	10.82	1.43	10.65	1.40	10.76	1.50	10.67	1.54	10.84	1.64	11.01	1.68	11.12	1.79	12.59	1.80	15.10	2.19

Table 19. Body Condition Index of juvenile coho salmon fed a normal regime in experimental tanks, determined every 21-d, n=20 per tank, at the Capilano Salmon Hatchery, 2001-2002.

	Body Condition Index																			
Tank	**21-Nov**		**12-Dec**		**02-Jan**		**23-Jan**		**13-Feb**		**06-Mar**		**27-Mar**		**17-Apr**		**08-May**		**29-May**	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	1.22	0.05	1.11	0.04	1.10	0.05	1.09	0.05	1.08	0.06	1.08	0.06	1.07	0.07	1.07	0.08	1.09	0.07	1.12	0.06
2	1.20	0.05	1.10	0.04	1.08	0.04	1.06	0.05	1.05	0.05	1.06	0.06	1.06	0.06	1.06	0.07	1.07	0.08	1.10	0.06
3	1.19	0.04	1.09	0.04	1.07	0.04	1.06	0.04	1.05	0.05	1.06	0.05	1.06	0.06	1.05	0.07	1.07	0.06	1.07	0.07
4	1.20	0.05	1.11	0.06	1.08	0.05	1.08	0.06	1.06	0.05	1.06	0.07	1.06	0.07	1.06	0.07	1.08	0.08	1.08	0.11
5	1.22	0.07	1.11	0.05	1.08	0.04	1.09	0.06	1.07	0.05	1.07	0.05	1.07	0.05	1.07	0.06	1.09	0.07	1.10	0.07
6	1.21	0.06	1.09	0.05	1.06	0.05	1.07	0.05	1.06	0.05	1.07	0.06	1.06	0.06	1.05	0.07	1.08	0.07	1.10	0.07
7	1.21	0.05	1.10	0.04	1.07	0.04	1.07	0.03	1.06	0.04	1.07	0.05	1.07	0.05	1.06	0.06	1.12	0.09	1.09	0.06
8	1.20	0.06	1.10	0.05	1.08	0.04	1.09	0.04	1.07	0.04	1.07	0.06	1.07	0.06	1.09	0.07	1.11	0.05	1.12	0.06
9	1.20	0.06	1.09	0.04	1.08	0.06	1.07	0.06	1.06	0.06	1.07	0.07	1.06	0.07	1.06	0.07	1.09	0.08	1.09	0.08
10	1.19	0.06	1.09	0.05	1.06	0.05	1.06	0.05	1.04	0.05	1.07	0.06	1.05	0.06	1.04	0.05	1.08	0.05	1.09	0.06

Table 20. Mean mass of hatchery raised juvenile coho salmon at the Capilano Salmon Hatchery, 2001-2002.

Bcm 5A				Bcm 5B			
Date	Mass (g)	SD	n	Date	Mass (g)	SD	n
04-Nov	10.98*B	-	100	04-Nov	11.29*B	-	100
13-Nov	12.13	3.20	100	02-Dec	11.26*B	-	100
19-Nov	11.61	3.18	152	30-Dec	11.09*B	-	100
02-Dec	11.29*B	-	100	27-Jan	10.96*B	-	100
30-Dec	11.67*	-	100	24-Feb	12.17*B	-	100
24-Mar	14.36*B	-	100	24-Mar	10.69*B	-	100
30-May	18.91	4.33	100	21-Apr	13.04*B	-	100
09-Jun	17.76*	-	100	24-May	15.71	3.17	100

note: Fish in Bcm 5A were fed an augmented regime, as was the rest of the fish at the hatchery, while those held in Bcm 5B were kept on a normal regime.

*: Measurements by Capilano Salmon Hatchery staff; B: Bulk mass divided by n.

Table 21. Length, mass, RNA, DNA, protein and trigylceride content of juvenile coho salmon fed a normal or augmented regime in troughs at the Capilano Salmon Hatchery, 2001-2002.

	Date	Turbidity	Length		Mass		DNA Concentration		RNA Concentration		RNA: DNA Ratio		Protein Concentration		Triglyceride Concentration	
		(NTU)	(mm)		(g)		($ngmg^{-1}$)		($ngmg^{-1}$)				(μgmg^{-1})		($\mu molg^{-1}$)	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Normal Regime	27-Nov	6.09	96.9	5.9	9.84	1.82	0.75	0.20	3.22	0.70	4.37	0.72	41.39	4.98	7.79	1.40
	08-Jan	11.60	94.9	5.9	8.94	1.56	0.80	0.24	3.02	0.80	4.32	2.31	40.72	5.05	6.04	1.63
	19-Feb	2.98	100.6	6.0	10.30	1.74	0.64	0.13	2.83	0.50	4.56	1.16	39.14	4.96	6.66	1.64
	02-Apr	2.47	98.2	6.2	9.47	2.05	0.59	0.08	2.16	0.32	3.70	0.60	40.27	8.86	4.86	1.62
	14-May	1.99	106.6	5.7	13.09	2.25	0.59	0.14	3.25	0.51	5.61	0.94	39.58	3.54	5.82	2.10
Augmented Regime	27-Nov	6.07	98.6	7.0	9.92	2.22	1.03	0.23	2.56	0.43	2.55	0.46	40.38	4.32	6.96	1.25
	08-Jan	11.10	95.4	4.3	9.01	1.49	0.64	0.17	3.38	0.67	5.41	0.78	42.12	4.35	6.86	1.25
	19-Feb	2.88	99.4	7.7	9.85	2.66	0.84	0.17	2.69	0.47	3.29	0.82	35.57	3.62	6.44	1.52
	02-Apr	2.48	104.0	5.7	11.95	1.99	0.46	0.13	2.82	0.42	6.50	1.99	40.53	4.04	6.82	1.75
	14-May	2.06	111.2	8.7	14.87	4.40	0.57	0.09	3.03	0.42	5.50	1.40	36.07	6.89	4.76	1.73

note: Turbidity determined in tank at time of fish removal.

Table 22. Water quality parameters determined at the time of the cover response trials at the Capilano Salmon Hatchery, 2002.

Date	Cover Response Tank		Troughs			
	Temperature	Turbidity	Temperature	Present Turbidity	Cumulative Mean Turbidity	Exposure Duration
	(° C)	(NTU)	(° C)	(NTU)	(NTU)	(h)
31-Jan	3.4	6.97	1.7	5.55	9.05	1656
21-Feb	4.2	3.63	2.7	3.12	7.80	2160
14-Mar	4.2	6.30	2.4	5.78	7.90	2664
04-Apr	5.0	6.28	3.6	3.08	7.10	3168
25-Apr	6.3	6.02	5.2	3.67	6.60	3672
16-May	8.1	3.87	6.9	1.82	6.10	4176

Table 23. Light intensity determined prior to each trial in the cover response tank at the Capilano Salmon Hatchery, 2002.

Light Intensity ($\mu Es^{-1}m^{-2}$)													
Date	31-Jan		19-Feb		13-Mar		02-Apr		23-Apr		16-May		Overall
Distance (cm)	1	2	1	2	1	2	1	2	1	2	1	2	Mean
75 Left*	2.14	2.21	2.16	2.28	2.30	2.35	2.50	2.38	1.82	1.94	2.13	2.06	2.19
60 Left	4.21	4.25	4.38	4.39	4.36	4.34	4.66	4.87	4.39	4.45	5.36	5.50	4.60
40 Left	5.78	5.77	5.99	5.96	6.22	6.19	5.97	6.11	6.34	6.45	6.91	6.88	6.21
20 Left	6.04	5.89	6.44	6.48	6.63	6.64	6.38	6.42	6.74	6.83	7.06	7.00	6.55
0*	6.06	6.07	6.47	6.40	6.55	6.52	6.75	6.79	6.30	6.36	7.06	7.08	6.53
20 Right	6.38	6.38	6.47	6.45	6.58	6.59	6.82	6.80	6.48	6.58	6.92	6.86	6.61
40 Right	5.99	5.94	5.95	5.89	6.04	6.08	6.20	6.13	5.91	6.01	6.59	6.63	6.11
60 Right	5.11	4.90	4.58	4.67	4.50	4.48	4.80	4.83	4.70	4.78	5.09	4.97	4.78
75 Right*	2.91	3.54	2.48	2.41	2.34	2.37	2.69	2.52	1.84	1.99	2.44	2.38	2.49
Trial Mean	4.98		4.99		5.06		5.20		5.00		5.50		5.12

*: 0 = point of entry of fish, 75 = black/white boundary

Note: 1 and 2 indicate opposite sides of tank.

Table 24. Mean length, mass, time, distance and speed (cms-1, bodylengthss-1) of juvenile coho salmon in response to cover 75 cm away, in trials conducted at the Capilano Salmon Hatchery (n=10; pooled: n=20).

Augmented Regime

Trough	1							2							Pooled						
Trial #	Length	Mass	Time	Distance		Speed		Length	Mass	Time	Distance		Speed		Length	Mass	Time	Distance		Speed	
				Milar	Trough						Milar	Trough						Milar	Trough		
	(mm)	(g)	(s)	(cm)	(cm)	(cms^{-1})	(bls^{-1})	(mm)	(g)	(s)	(cm)	(cm)	(cms^{-1})	(bls^{-1})	(mm)	(g)	(s)	(cm)	(cm)	(cms^{-1})	(bls^{-1})
1	96.8	9.33	3.05	16.60	90.47	32.67	3.36	96.1	9.26	2.56	16.80	91.56	37.06	3.90	96.45	9.29	2.80	16.70	91.02	34.87	3.63
2	95.7	9.26	2.00	16.05	87.47	46.76	4.91	99.8	10.44	2.21	17.25	94.01	49.97	5.00	97.75	9.85	2.10	16.65	90.74	48.37	4.96
3	101.6	11.54	2.03	16.00	87.20	46.59	4.59	103.5	11.85	3.66	18.55	101.10	38.82	3.77	102.55	11.69	2.85	17.28	94.15	42.70	4.18
4	101.1	10.96	2.87	16.25	88.56	42.17	4.17	100.2	10.76	2.24	16.50	89.93	48.92	4.85	100.65	10.86	2.55	16.38	89.24	45.54	4.51
5	103	11.35	1.76	16.85	91.83	55.59	5.41	105.1	12.71	1.95	16.70	91.02	50.11	4.79	104.05	12.03	1.85	16.78	91.42	52.85	5.10
6	109.5	14.02	2.06	16.95	92.38	58.01	5.29	112.1	14.81	4.00	17.75	96.74	47.81	4.26	106.30	12.35	1.54	16.48	89.79	70.56	6.70
Overall	101.3	11.08	2.29	16.45	89.65	46.97	4.62	102.8	11.64	2.77	17.26	94.06	45.45	4.43	101.29	11.01	2.28	16.71	91.06	49.15	4.85

Normal Regime

Trough	3							4							Pooled						
Trial #	Length	Mass	Time	Distance		Speed		Length	Mass	Time	Distance		Speed		Length	Mass	Time	Distance		Speed	
				Milar	Trough						Milar	Trough						Milar	Trough		
	(mm)	(g)	(s)	(cm)	(cm)	(cms^{-1})	(bls^{-1})	(mm)	(g)	(s)	(cm)	(cm)	(cms^{-1})	(bls^{-1})	(mm)	(g)	(s)	(cm)	(cm)	(cms^{-1})	(bls^{-1})
1	98.5	9.63	1.65	16.50	89.93	60.30	6.15	99.6	9.95	3.44	17.35	94.56	32.46	3.26	99.05	9.79	2.54	16.93	92.24	46.38	4.70
2	96.1	9.17	1.63	16.35	89.11	66.05	6.94	96.8	9.57	1.93	16.65	90.74	54.37	5.63	96.45	9.37	1.78	16.50	89.93	60.21	6.28
3	98.1	9.73	2.18	16.00	87.20	43.53	4.42	101.2	10.96	2.53	16.85	91.83	38.52	3.81	99.65	10.34	2.35	16.43	89.52	41.02	4.12
4	99.1	9.84	1.77	15.25	83.11	55.54	5.66	98.8	10.15	1.69	16.10	87.75	56.22	5.65	98.95	9.99	1.73	15.68	85.43	55.88	5.65
5	99.4	9.96	1.51	16.45	89.65	63.87	6.42	102.7	11.35	1.71	18.55	101.10	62.33	6.10	101.05	10.66	1.61	17.50	95.38	63.10	6.26
6	105.5	12.43	1.28	16.50	89.93	77.19	7.36	107.1	12.26	1.81	16.45	89.65	63.94	6.04	110.8	14.42	3.03	17.35	94.56	52.91	4.77
Overall	99.45	10.13	1.67	16.18	88.15	61.08	6.16	101.03	10.71	2.18	16.99	92.60	51.31	5.08	100.99	10.76	2.17	16.73	91.17	53.25	5.30

note: 'Milar' indicates distance traced onto transparency film.

Table 25. Calculations of Severity of Ill Effect scores following exposure of juvenile coho salmon to suspended sediment at the Capilano Salmon Hatchery, 2001-2002.

		Within Sampling Period				From Start of Experimentation			
Sampling Period Start Date	Trough	Turbidity (NTU)	SS (mgL^{-1})	Exposure Duration (h)	Severity of Ill Effect Score	Turbidity (NTU)	SS (mgL^{-1})	Exposure Duration (h)	Severity of Ill Effect Score
22-Nov-01	1	5.16	2.27	504	5.69	5.16	2.27	504	5.69
	2	5.23	2.34	504	5.71	5.23	2.34	504	5.71
	3	5.10	2.20	504	5.67	5.10	2.20	504	5.67
	4	5.03	2.13	504	5.64	5.03	2.13	504	5.64
13-Dec-01	1	11.26	8.64	504	6.64	7.87	5.10	1008	6.75
	2	11.33	8.70	504	6.65	7.94	5.17	1008	6.76
	3	11.22	8.59	504	6.64	7.82	5.04	1008	6.75
	4	11.46	8.84	504	6.66	7.89	5.12	1008	6.76
03-Jan-02	1	11.62	9.00	504	6.67	9.21	6.49	1512	7.21
	2	11.96	9.37	504	6.70	9.38	6.67	1512	7.23
	3	11.68	9.07	504	6.68	9.20	6.48	1512	7.21
	4	11.73	9.12	504	6.68	9.26	6.55	1512	7.22
24-Jan-02	1	5.29	2.40	504	5.73	8.18	5.42	2016	7.29
	2	5.29	2.40	504	5.73	8.30	5.54	2016	7.30
	3	5.27	2.38	504	5.72	8.16	5.40	2016	7.28
	4	5.28	2.39	504	5.73	8.21	5.45	2016	7.29
14-Feb-02	1	5.44	2.56	504	5.77	7.61	4.82	2520	7.36
	2	5.49	2.61	504	5.79	7.71	4.93	2520	7.38
	3	5.50	2.62	504	5.79	7.61	4.82	2520	7.36
	4	5.58	2.71	504	5.81	7.67	4.88	2520	7.37
07-Mar-02	1	4.86	1.95	504	5.58	7.13	4.33	3024	7.41
	2	4.81	1.90	504	5.56	7.21	4.41	3024	7.42
	3	4.83	1.93	504	5.57	7.13	4.32	3024	7.41
	4	4.84	1.93	504	5.57	7.18	4.37	3024	7.42
28-Mar-02	1	3.29	0.31	504	4.27	6.63	3.80	3528	7.43
	2	3.28	0.30	504	4.25	6.70	3.88	3528	7.44
	3	3.35	0.38	504	4.41	6.64	3.81	3528	7.43
	4	3.31	0.33	504	4.31	6.67	3.85	3528	7.43

Table 25. Calculations of Severity of Ill Effect scores following exposure of juvenile coho salmon to suspended sediment at the Capilano Salmon Hatchery, 2001-2002.

		Within Sampling Period				From Start of Experimentation			
Sampling Period Start Date	Trough	Turbidity (NTU)	SS (mgL^{-1})	Exposure Duration (h)	Severity of Ill Effect Score	Turbidity (NTU)	SS (mgL^{-1})	Exposure Duration (h)	Severity of Ill Effect Score
18-Apr-02	1	3.55	0.59	504	4.72	6.26	3.42	4032	7.44
	2	3.51	0.54	504	4.67	6.32	3.48	4032	7.46
	3	3.49	0.52	504	4.64	6.26	3.42	4032	7.44
	4	3.51	0.55	504	4.67	6.30	3.45	4032	7.45
09-May-02	1	1.68	-1.36	504	n/a	5.74	2.87	4536	7.40
	2	1.69	-1.35	504	n/a	5.79	2.92	4536	7.41
	3	1.67	-1.38	504	n/a	5.73	2.87	4536	7.40
	4	1.65	-1.39	504	n/a	5.76	2.89	4536	7.41

Table 26. Severity of Ill Effect scores following exposure of juvenile coho salmon to suspended sediment at Capilano Salmon Hatchery, 2001-2002.

		Within Sampling Period				From Start of Experimentation			
Sampling Period Start Date	Tank	Turbidity (NTU)	SS (mgL^{-1})	Exposure Duration (h)	Severity of Ill Effect Score	Turbidity (NTU)	SS (mgL^{-1})	Exposure Duration (h)	Severity of Ill Effect Score
21-Nov-01	1	5.56	2.69	504	5.81	5.56	2.69	504	5.81
	2	5.52	2.64	504	5.80	5.52	2.64	504	5.80
	3	5.58	2.70	504	5.81	5.58	2.70	504	5.81
	4	5.48	2.60	504	5.79	5.48	2.60	504	5.79
	5	5.54	2.66	504	5.80	5.54	2.66	504	5.80
	6	5.45	2.57	504	5.78	5.45	2.57	504	5.78
	7	5.52	2.64	504	5.80	5.52	2.64	504	5.80
	8	5.59	2.71	504	5.82	5.59	2.71	504	5.82
	9	5.56	2.68	504	5.81	5.56	2.68	504	5.81
	10	5.56	2.69	504	5.81	5.56	2.69	504	5.81
12-Dec-01	1	10.83	8.19	504	6.61	7.90	5.13	1008	6.76
	2	10.72	8.07	504	6.59	7.83	5.05	1008	6.75
	3	10.96	8.32	504	6.62	7.97	5.20	1008	6.77
	4	10.72	8.06	504	6.59	7.81	5.03	1008	6.74
	5	10.81	8.16	504	6.60	7.88	5.11	1008	6.76
	6	11.05	8.42	504	6.62	7.94	5.17	1008	6.76
	7	10.88	8.24	504	6.61	7.90	5.13	1008	6.76
	8	10.75	8.10	504	6.60	7.88	5.11	1008	6.76
	9	10.61	7.95	504	6.58	7.80	5.02	1008	6.74
	10	10.81	8.17	504	6.60	7.90	5.12	1008	6.76
02-Jan-02	1	11.53	8.91	504	6.67	9.20	6.48	1512	7.21
	2	11.44	8.82	504	6.66	9.12	6.40	1512	7.20
	3	11.59	8.97	504	6.67	9.26	6.55	1512	7.22
	4	11.53	8.91	504	6.67	9.14	6.42	1512	7.20
	5	11.49	8.88	504	6.66	9.17	6.45	1512	7.21
	6	11.72	9.11	504	6.68	9.29	6.57	1512	7.22
	7	11.71	9.10	504	6.68	9.26	6.55	1512	7.22
	8	11.63	9.02	504	6.67	9.22	6.50	1512	7.21
	9	11.73	9.12	504	6.68	9.20	6.49	1512	7.21
	10	11.61	8.99	504	6.67	9.22	6.50	1512	7.21

Table 26. Severity of Ill Effect scores following exposure of juvenile coho salmon to suspended sediment at Capilano Salmon Hatchery, 2001-2002.

		Within Sampling Period				From Start of Experimentation			
Sampling Period Start Date	Tank	Turbidity (NTU)	SS (mgL^{-1})	Exposure Duration (h)	Severity of Ill Effect Score	Turbidity (NTU)	SS (mgL^{-1})	Exposure Duration (h)	Severity of Ill Effect Score
23-Jan-02	1	5.54	2.66	504	5.80	8.34	5.58	2016	7.31
	2	5.46	2.58	504	5.78	8.26	5.50	2016	7.30
	3	5.50	2.62	504	5.79	8.38	5.62	2016	7.31
	4	5.44	2.56	504	5.77	8.27	5.51	2016	7.30
	5	5.51	2.63	504	5.79	8.31	5.55	2016	7.30
	6	5.40	2.52	504	5.76	8.37	5.62	2016	7.31
	7	5.50	2.63	504	5.79	8.38	5.63	2016	7.31
	8	5.43	2.55	504	5.77	8.32	5.57	2016	7.31
	9	5.52	2.64	504	5.80	8.34	5.58	2016	7.31
	10	5.53	2.65	504	5.80	8.35	5.60	2016	7.31
13-Feb-02	1	5.17	2.28	504	5.69	7.60	4.81	2520	7.36
	2	5.19	2.29	504	5.70	7.54	4.75	2520	7.35
	3	5.08	2.18	504	5.66	7.61	4.82	2520	7.36
	4	5.16	2.27	504	5.69	7.54	4.75	2520	7.35
	5	5.11	2.21	504	5.67	7.56	4.77	2520	7.35
	6	5.18	2.28	504	5.69	7.62	4.84	2520	7.36
	7	5.15	2.25	504	5.68	7.62	4.84	2520	7.36
	8	5.24	2.35	504	5.71	7.60	4.81	2520	7.36
	9	5.06	2.16	504	5.65	7.57	4.78	2520	7.35
	10	5.18	2.29	504	5.70	7.61	4.82	2520	7.36
06-Mar-02	1	4.92	2.02	504	5.60	7.14	4.33	3024	7.41
	2	4.92	2.02	504	5.60	7.09	4.28	3024	7.40
	3	4.89	1.99	504	5.59	7.14	4.33	3024	7.41
	4	4.96	2.06	504	5.62	7.09	4.28	3024	7.40
	5	4.89	1.99	504	5.59	7.10	4.29	3024	7.40
	6	5.02	2.12	504	5.64	7.17	4.37	3024	7.42
	7	5.04	2.14	504	5.65	7.18	4.37	3024	7.42
	8	4.97	2.07	504	5.62	7.15	4.34	3024	7.41
	9	5.00	2.10	504	5.63	7.13	4.32	3024	7.41
	10	5.08	2.18	504	5.66	7.17	4.37	3024	7.42

Table 26. Severity of Ill Effect scores following exposure of juvenile coho salmon to suspended sediment at Capilano Salmon Hatchery, 2001-2002.

		Within Sampling Period				From Start of Experimentation			
Sampling Period Start Date	Tank	Turbidity (NTU)	SS (mgL^{-1})	Exposure Duration (h)	Severity of Ill Effect Score	Turbidity (NTU)	SS (mgL^{-1})	Exposure Duration (h)	Severity of Ill Effect Score
27-Mar-02	1	3.04	0.05	504	2.95	6.60	3.77	3528	7.42
	2	3.08	0.09	504	3.42	6.57	3.73	3528	7.41
	3	2.98	-0.01	504	n/a	6.60	3.77	3528	7.42
	4	3.03	0.04	504	2.77	6.56	3.73	3528	7.41
	5	3.05	0.06	504	3.08	6.57	3.74	3528	7.41
	6	3.09	0.10	504	3.47	6.64	3.81	3528	7.43
	7	3.07	0.08	504	3.34	6.64	3.81	3528	7.43
	8	3.10	0.11	504	3.55	6.62	3.79	3528	7.42
	9	3.03	0.05	504	2.90	6.60	3.77	3528	7.42
	10	3.07	0.08	504	3.31	6.64	3.81	3528	7.43
17-Apr-02	1	3.72	0.77	504	4.91	6.23	3.38	4032	7.44
	2	3.64	0.68	504	4.83	6.18	3.34	4032	7.43
	3	3.64	0.68	504	4.83	6.21	3.36	4032	7.43
	4	3.72	0.76	504	4.91	6.19	3.34	4032	7.43
	5	3.66	0.70	504	4.85	6.19	3.34	4032	7.43
	6	3.62	0.66	504	4.81	6.25	3.40	4032	7.44
	7	3.73	0.78	504	4.92	6.26	3.42	4032	7.44
	8	3.77	0.81	504	4.96	6.25	3.40	4032	7.44
	9	3.65	0.69	504	4.84	6.21	3.36	4032	7.43
	10	3.72	0.77	504	4.91	6.26	3.41	4032	7.44
08-May-02	1	1.70	-1.35	504	n/a	5.74	2.87	4536	7.40
	2	1.71	-1.34	504	n/a	5.73	2.86	4536	7.40
	3	1.72	-1.32	504	n/a	5.72	2.86	4536	7.40
	4	1.80	-1.25	504	n/a	5.72	2.85	4536	7.40
	5	1.73	-1.32	504	n/a	5.71	2.84	4536	7.39
	6	1.73	-1.31	504	n/a	5.76	2.89	4536	7.41
	7	1.77	-1.27	504	n/a	5.78	2.91	4536	7.41
	8	1.73	-1.31	504	n/a	5.76	2.89	4536	7.41
	9	1.72	-1.32	504	n/a	5.73	2.86	4536	7.40
	10	1.73	-1.32	504	n/a	5.77	2.90	4536	7.41

Table 27. Total monthly precipitation at the North Vancouver Cleveland Weather Station, November 2001- June 2002, and corresponding 30 y averages, Environment Canada.

	Total Monthly Precipitation (mm)	
Month	Actual (2001-2002)	Average (1971-2000)
November	262.1	383.1
December	362.5	348.9
January	347.2	302.4
February	219.2	262.6
March	233.7	221.4
April	194.3	159.9
May	163.2	139.1
June	82.6	114.2

Table 28. Summary of selected data on water quality, fish and food ration in experimental troughs at the Capilano River Hatchery from November 22, 2001 to May 30 2002

Trough	Period Start Date	22-Nov	13-Dec	#####	24-Jan	14-Feb	#####	28-Mar	18-Apr	#####	30-May
1	Body Condition Index	1.11	1.08	1.05	1.05	1.05	1.09	1.11	1.13	1.09	1.09
	Length (mm)	97.38	97.92	99.00	98.10	98.96	100.74	101.06	105.00	109.70	117.34
	Mass (g)	10.35	10.28	10.31	10.02	10.24	11.27	11.59	13.23	14.57	17.76
	Turbidity (NTU)	5.16	11.26	11.62	5.29	5.44	4.86	3.29	3.55	1.68	-
	Temperature (° C)	5.66	2.58	3.14	2.03	2.57	2.51	3.82	5.46	6.63	-
	% Bodymass fed per day	0.58%	0.18%	0.29%	0.15%	0.25%	0.24%	0.40%	0.69%	0.91%	-
	% Bodymass ration recommended by Stauffer's	1.62%	0.51%	0.80%	0.42%	0.70%	0.69%	1.11%	1.58%	1.81%	-
	% Bodymass ration recommended by EWOS	1.41%	1.02%	1.18%	0.96%	1.09%	1.09%	1.29%	1.38%	1.44%	-
	% Change in mass per day	-0.03%	0.01%	-0.13%	0.10%	0.48%	0.14%	0.67%	0.48%	1.04%	-
2	Body Condition Index	1.10	1.09	1.06	1.08	1.06	1.09	1.11	1.12	1.09	1.08
	Length (mm)	97.54	98.80	97.80	98.50	98.36	100.18	103.02	103.32	110.44	118.34
	Mass (g)	10.29	10.64	10.05	10.43	10.18	11.10	12.32	12.45	14.89	18.07
	Turbidity (NTU)	5.23	11.33	11.96	5.29	5.49	4.81	3.28	3.51	1.69	-
	Temperature (° C)	5.67	2.58	3.14	2.03	2.57	2.51	3.82	5.45	6.63	-
	% Bodymass fed per day	0.58%	0.18%	0.29%	0.15%	0.25%	0.25%	0.39%	0.70%	0.89%	-
	% Bodymass ration recommended by Stauffer's	1.63%	0.51%	0.81%	0.41%	0.69%	0.70%	1.09%	1.61%	1.79%	-
	% Bodymass ration recommended by EWOS	1.41%	1.02%	1.18%	0.96%	1.09%	1.09%	1.29%	1.38%	1.44%	-
	% Change in mass per day	0.16%	-0.26%	0.18%	-0.11%	0.43%	0.52%	0.05%	0.93%	1.02%	-
3	Body Condition Index	1.12	1.07	1.05	1.06	1.02	1.05	1.05	1.02	1.14	1.07
	Length (mm)	96.94	97.44	98.10	97.40	98.04	98.78	98.66	99.26	102.20	111.50
	Mass (g)	10.23	10.01	10.09	9.91	9.76	10.27	10.10	10.15	12.33	14.89
	Turbidity (NTU)	5.10	11.22	11.68	5.27	5.50	4.83	3.35	3.49	1.67	-
	Temperature (° C)	5.67	2.59	3.15	2.04	2.56	2.51	3.81	5.45	6.63	-
	% Bodymass fed per day	0.12%	0.04%	0.06%	0.03%	0.05%	0.05%	0.11%	0.69%	0.94%	-
	% Bodymass ration recommended by Stauffer's	1.62%	0.54%	0.83%	0.38%	0.71%	0.71%	1.17%	1.67%	1.87%	-
	% Bodymass ration recommended by EWOS	1.41%	1.02%	1.16%	0.94%	1.09%	1.09%	1.29%	1.38%	1.44%	-
	% Change in mass per day	-0.10%	0.04%	-0.08%	-0.08%	0.25%	-0.08%	0.02%	1.02%	0.99%	-
4	Body Condition Index	1.11	1.08	1.05	1.07	1.05	1.06	1.06	1.02	1.13	1.05
	Length (mm)	97.62	96.56	98.00	97.58	98.22	99.52	98.56	98.96	103.04	112.00
	Mass (g)	10.39	9.80	10.05	10.05	10.10	10.56	10.24	10.11	12.46	14.93
	Turbidity (NTU)	5.03	11.46	11.73	5.28	5.58	4.84	3.31	3.51	1.65	-
	Temperature (° C)	5.67	2.58	3.14	2.03	2.57	2.51	3.82	5.46	6.63	-
	% Bodymass fed per day	0.12%	0.04%	0.06%	0.03%	0.05%	0.05%	0.11%	0.72%	0.95%	-
	% Bodymass ration recommended by Stauffer's	1.61%	0.54%	0.83%	0.38%	0.70%	0.71%	1.16%	1.73%	1.89%	-
	% Bodymass ration recommended by EWOS	1.41%	1.02%	1.16%	0.94%	1.09%	1.09%	1.29%	1.38%	1.44%	-
	% Change in mass per day	-0.27%	0.12%	0.00%	0.03%	0.21%	-0.14%	-0.06%	1.11%	0.89%	-

Table 29. Summary of selected data on water quality, fish and food ration in experimental tanks at the Capilano Salmon Hatchery from November 21, 2001 to May 29, 2002.

Tank	Period Start Date	21-Nov	12-Dec	02-Jan	23-Jan	13-Feb	06-Mar	27-Mar	17-Apr	08-May	29-May
1	Body Condition Index	1.22	1.11	1.10	1.09	1.08	1.08	1.07	1.07	1.09	1.12
	Length (mm)	98.4	99.7	99.9	100.3	100.4	100.9	101.5	102.2	104.7	111.1
	Mass (g)	11.63	11.07	11.02	11.04	10.95	11.14	11.20	11.52	12.62	15.47
	Turbidity (NTU)	5.6	10.8	11.5	5.5	5.2	4.9	3.0	3.7	1.7	1.2
	Temperature (° C)	5.9	2.7	3.2	2.0	2.5	2.5	3.8	5.3	6.6	6.7
	% Bodymass fed per day	0.11%	0.04%	0.06%	0.03%	0.05%	0.05%	0.11%	0.69%	0.94%	-
	% Bodymass ration recommended by Stauffer's	1.55%	0.51%	0.81%	0.36%	0.68%	0.69%	1.13%	1.66%	1.89%	-
	% Bodymass ration recommended by EWOS	1.41%	1.02%	1.16%	0.94%	1.09%	1.09%	1.29%	1.38%	1.44%	-
	% Change in mass per day	-0.23%	-0.02%	0.01%	-0.04%	0.08%	0.03%	0.13%	0.46%	1.08%	-
2	Body Condition Index	1.20	1.10	1.08	1.06	1.05	1.06	1.06	1.06	1.07	1.10
	Length (mm)	98.50	100.37	100.47	100.95	101.05	101.26	101.84	102.21	105.58	111.68
	Mass (g)	11.48	11.15	11.00	10.94	10.91	11.02	11.23	11.37	12.72	15.51
	Turbidity (NTU)	5.52	10.72	11.44	5.46	5.19	4.92	3.08	3.64	1.71	1.12
	Temperature (° C)	3.17	2.04	2.54	2.49	3.79	5.31	6.60	5.87	2.74	6.70
	% Bodymass fed per day	0.11%	0.04%	0.06%	0.03%	0.05%	0.05%	0.11%	0.69%	0.94%	-
	% Bodymass ration recommended by Stauffer's	1.56%	0.51%	0.81%	0.36%	0.68%	0.70%	1.12%	1.66%	1.88%	-
	% Bodymass ration recommended by EWOS	1.41%	1.02%	1.16%	0.94%	1.09%	1.09%	1.29%	1.38%	1.44%	-
	% Change in mass per day	-0.14%	-0.06%	-0.03%	-0.01%	0.05%	0.09%	0.06%	0.57%	1.05%	-
3	Body Condition Index	1.19	1.09	1.07	1.06	1.05	1.06	1.06	1.05	1.07	1.07
	Length (mm)	98.65	99.75	100.10	100.50	100.70	100.95	101.40	102.05	105.00	110.65
	Mass (g)	11.46	10.93	10.78	10.82	10.75	11.04	11.11	11.31	12.49	14.65
	Turbidity (NTU)	5.58	10.96	11.59	5.50	5.08	4.89	2.98	3.64	1.72	1.05
	Temperature (° C)	2.04	2.54	2.49	3.79	5.31	6.61	5.87	2.74	3.17	6.70
	% Bodymass fed per day	0.11%	0.04%	0.06%	0.03%	0.05%	0.05%	0.11%	0.69%	0.95%	-
	% Bodymass ration recommended by Stauffer's	1.56%	0.51%	0.81%	0.36%	0.68%	0.70%	1.13%	1.66%	1.89%	-
	% Bodymass ration recommended by EWOS	1.41%	1.02%	1.16%	0.94%	1.09%	1.09%	1.29%	1.38%	1.44%	-
	% Change in mass per day	-0.22%	-0.07%	0.02%	-0.03%	0.13%	0.03%	0.08%	0.50%	0.82%	-

Table 29. Summary of selected data on water quality, fish and food ration in experimental tanks at the Capilano Salmon Hatchery from November 21, 2001 to May 29, 2002.

Tank	Period Start Date	21-Nov	12-Dec	02-Jan	23-Jan	13-Feb	06-Mar	27-Mar	17-Apr	08-May	29-May
4	Body Condition Index	1.20	1.11	1.08	1.08	1.06	1.06	1.06	1.06	1.08	1.08
	Length (mm)	98.35	99.40	99.80	99.95	100.30	100.70	100.95	101.65	104.45	109.85
	Mass (g)	11.48	10.90	10.78	10.85	10.75	10.92	10.95	11.20	12.42	14.45
	Turbidity (NTU)	5.48	10.72	11.53	5.44	5.16	4.96	3.03	3.72	1.80	1.12
	Temperature (° C)	2.54	2.49	3.79	5.31	6.61	5.87	2.73	3.15	2.02	6.70
	% Bodymass fed per day	0.11%	0.04%	0.06%	0.03%	0.05%	0.05%	0.11%	0.69%	0.95%	-
	% Bodymass ration recommended by Stauffer's	1.56%	0.51%	0.81%	0.36%	0.68%	0.70%	1.13%	1.67%	1.90%	-
	% Bodymass ration recommended by EWOS	1.41%	1.02%	1.16%	0.94%	1.09%	1.09%	1.29%	1.38%	1.44%	-
	% Change in mass per day	-0.24%	-0.05%	0.03%	-0.05%	0.08%	0.01%	0.11%	0.52%	0.78%	-
5	Body Condition Index	1.22	1.11	1.08	1.09	1.07	1.07	1.07	1.07	1.09	1.10
	Length (mm)	98.85	100.20	100.55	100.65	101.15	101.55	101.85	102.40	104.95	111.10
	Mass (g)	11.89	11.22	11.06	11.15	11.11	11.23	11.33	11.55	12.67	15.17
	Turbidity (NTU)	5.54	10.81	11.49	5.51	5.11	4.89	3.05	3.66	1.73	1.25
	Temperature (° C)	2.49	3.78	5.31	6.58	5.87	2.73	3.15	2.02	2.54	6.70
	% Bodymass fed per day	0.11%	0.04%	0.06%	0.03%	0.05%	0.05%	0.11%	0.69%	0.94%	-
	% Bodymass ration recommended by Stauffer's	1.54%	0.51%	0.81%	0.36%	0.68%	0.69%	1.12%	1.65%	1.89%	-
	% Bodymass ration recommended by EWOS	1.41%	1.02%	1.16%	0.94%	1.09%	1.09%	1.29%	1.38%	1.44%	-
	% Change in mass per day	-0.27%	-0.07%	0.04%	-0.02%	0.05%	0.04%	0.09%	0.46%	0.94%	-
6	Body Condition Index	1.21	1.09	1.06	1.07	1.06	1.07	1.06	1.05	1.08	1.10
	Length (mm)	98.95	100.40	100.80	100.90	101.15	101.30	102.05	102.50	104.90	110.30
	Mass (g)	11.75	11.06	10.92	11.03	10.98	11.14	11.26	11.38	12.50	14.93
	Turbidity (NTU)	5.45	11.05	11.72	5.40	5.18	5.02	3.09	3.62	1.73	1.13
	Temperature (° C)	3.78	5.31	6.58	5.87	2.73	3.15	2.02	2.54	2.49	6.70
	% Bodymass fed per day	0.11%	0.04%	0.06%	0.03%	0.05%	0.05%	0.11%	0.69%	0.95%	-
	% Bodymass ration recommended by Stauffer's	1.54%	0.51%	0.81%	0.36%	0.68%	0.69%	1.12%	1.66%	1.89%	-
	% Bodymass ration recommended by EWOS	1.41%	1.02%	1.16%	0.94%	1.09%	1.09%	1.29%	1.38%	1.44%	-
	% Change in mass per day	-0.28%	-0.06%	0.05%	-0.02%	0.07%	0.05%	0.05%	0.47%	0.93%	-

Table 29. Summary of selected data on water quality, fish and food ration in experimental tanks at the Capilano Salmon Hatchery from November 21, 2001 to May 29, 2002.

Tank	Period Start Date	21-Nov	12-Dec	02-Jan	23-Jan	13-Feb	06-Mar	27-Mar	17-Apr	08-May	29-May
7	Body Condition Index	1.21	1.10	1.07	1.07	1.06	1.07	1.07	1.06	1.12	1.09
	Length (mm)	97.20	98.35	98.65	98.90	99.20	99.45	100.05	100.70	104.25	110.55
	Mass (g)	11.19	10.50	10.37	10.44	10.44	10.62	10.74	10.92	12.77	14.91
	Turbidity (NTU)	5.52	10.88	11.71	5.50	5.15	5.04	3.07	3.73	1.77	1.19
	Temperature (° C)	5.31	6.58	5.87	2.73	3.15	2.02	2.54	2.49	3.78	6.70
	% Bodymass fed per day	0.11%	0.04%	0.06%	0.03%	0.05%	0.05%	0.11%	0.70%	0.94%	-
	% Bodymass ration recommended by Stauffer's	1.57%	0.52%	0.82%	0.37%	0.69%	0.70%	1.14%	1.69%	1.88%	-
	% Bodymass ration recommended by EWOS	1.41%	1.02%	1.16%	0.94%	1.09%	1.09%	1.29%	1.38%	1.44%	-
	% Change in mass per day	-0.30%	-0.06%	0.03%	0.00%	0.09%	0.05%	0.08%	0.81%	0.80%	-
8	Body Condition Index	1.20	1.10	1.08	1.09	1.07	1.08	1.07	1.09	1.11	1.12
	Length (mm)	97.15	98.25	98.60	98.95	99.25	99.60	100.05	100.65	103.95	110.45
	Mass (g)	11.08	10.52	10.45	10.57	10.54	10.74	10.81	11.18	12.59	15.17
	Turbidity (NTU)	5.59	10.75	11.63	5.43	5.24	4.97	3.10	3.77	1.73	1.16
	Temperature (° C)	6.58	5.87	2.73	3.15	2.02	2.54	2.49	3.78	5.31	6.70
	% Bodymass fed per day	0.11%	0.04%	0.06%	0.03%	0.05%	0.05%	0.11%	0.69%	0.95%	-
	% Bodymass ration recommended by Stauffer's	1.58%	0.52%	0.82%	0.37%	0.69%	0.70%	1.14%	1.67%	1.89%	-
	% Bodymass ration recommended by EWOS	1.41%	1.02%	1.16%	0.94%	1.09%	1.09%	1.29%	1.38%	1.44%	-
	% Change in mass per day	-0.24%	-0.03%	0.05%	-0.01%	0.09%	0.03%	0.16%	0.60%	0.98%	-
9	Body Condition Index	1.20	1.09	1.08	1.07	1.06	1.07	1.06	1.06	1.09	1.09
	Length (mm)	97.45	98.70	99.00	99.25	99.45	99.70	100.20	100.90	103.35	108.20
	Mass (g)	11.24	10.59	10.55	10.56	10.47	10.69	10.70	10.97	12.13	13.89
	Turbidity (NTU)	5.56	10.61	11.73	5.52	5.06	5.00	3.03	3.65	1.72	1.09
	Temperature (° C)	5.87	2.74	3.17	2.04	2.54	2.49	3.79	5.32	6.61	6.70
	% Bodymass fed per day	0.11%	0.04%	0.06%	0.03%	0.05%	0.05%	0.11%	0.70%	0.96%	-
	% Bodymass ration recommended by Stauffer's	1.57%	0.52%	0.82%	0.37%	0.69%	0.70%	1.14%	1.68%	1.91%	-
	% Bodymass ration recommended by EWOS	1.41%	1.02%	1.16%	0.94%	1.09%	1.09%	1.29%	1.38%	1.44%	-
	% Change in mass per day	-0.28%	-0.02%	0.00%	-0.04%	0.10%	0.01%	0.12%	0.50%	0.69%	-

Table 29. Summary of selected data on water quality, fish and food ration in experimental tanks at the Capilano Salmon Hatchery from November 21, 2001 to May 29, 2002.

Tank	Period Start Date	21-Nov	12-Dec	02-Jan	23-Jan	13-Feb	06-Mar	27-Mar	17-Apr	08-May	29-May
10	Body Condition Index	1.19	1.09	1.06	1.06	1.04	1.05	1.05	1.04	1.08	1.09
	Length (mm)	98.35	99.70	99.90	100.25	100.55	100.85	101.20	102.00	105.05	111.20
	Mass (g)	11.43	10.82	10.65	10.76	10.67	10.84	11.01	11.12	12.59	15.10
	Turbidity (NTU)	5.56	10.81	11.61	5.53	5.18	5.08	3.07	3.72	1.73	1.19
	Temperature (° C)	2.74	3.17	2.04	2.54	2.49	3.79	5.31	6.61	5.88	6.70
	% Bodymass fed per day	0.11%	0.04%	0.06%	0.03%	0.05%	0.05%	0.11%	0.69%	0.94%	-
	% Bodymass ration recommended by Stauffer's	1.56%	0.51%	0.82%	0.36%	0.69%	0.70%	1.13%	1.68%	1.89%	-
	% Bodymass ration recommended by EWOS	1.41%	1.02%	1.16%	0.94%	1.09%	1.09%	1.29%	1.38%	1.44%	-
	% Change in mass per day	-0.26%	-0.07%	0.05%	-0.04%	0.08%	0.07%	0.05%	0.63%	0.95%	-

Figure 1. Birds eye view of experimental chamber (Bch 3) at the Capilano Salmon Hatchery, 2001-2002.

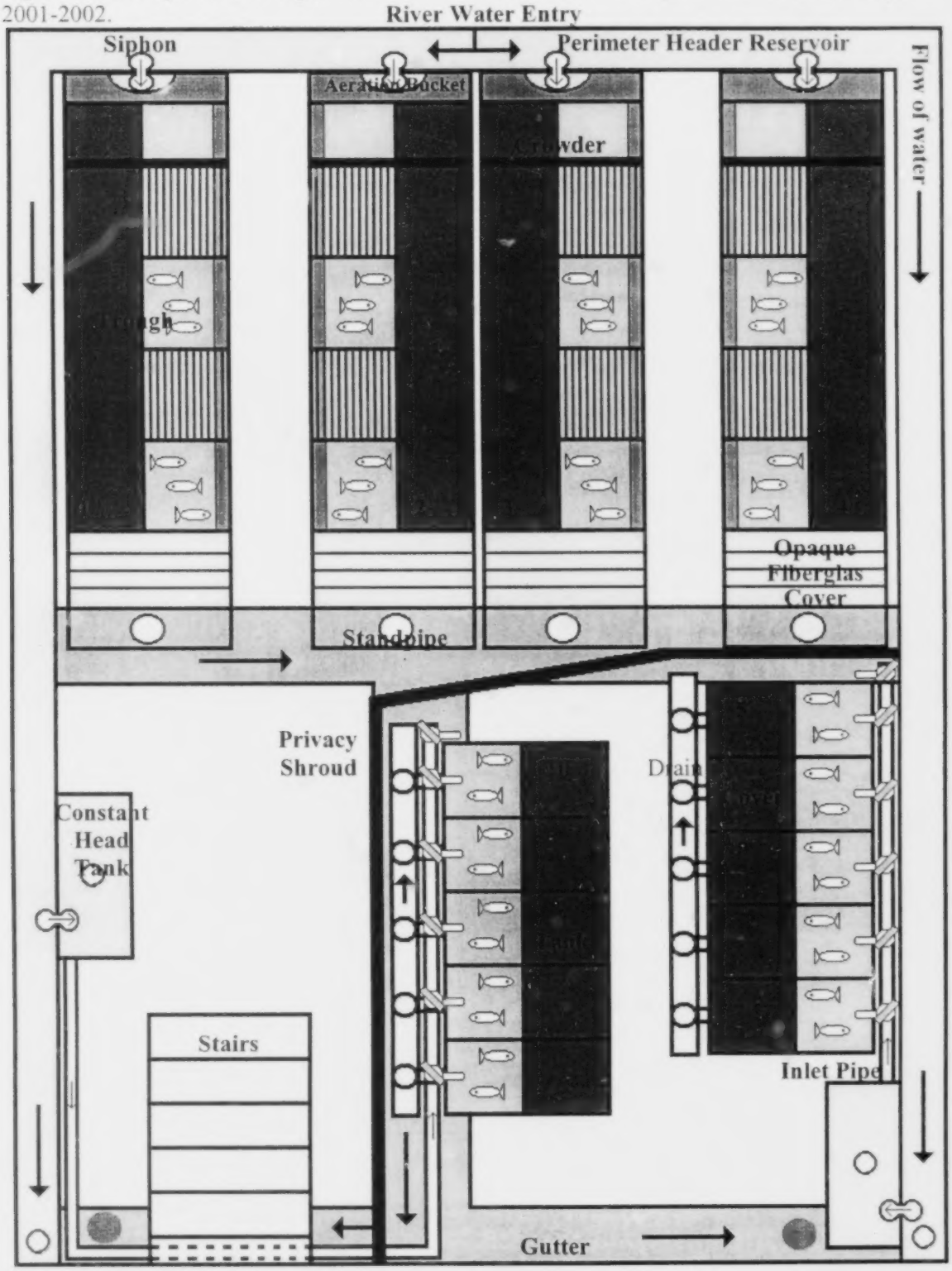


Figure 1. Birds eye view of experimental chamber (Beh 3) at the Capilano Salmon Hatchery, 2001-2002.

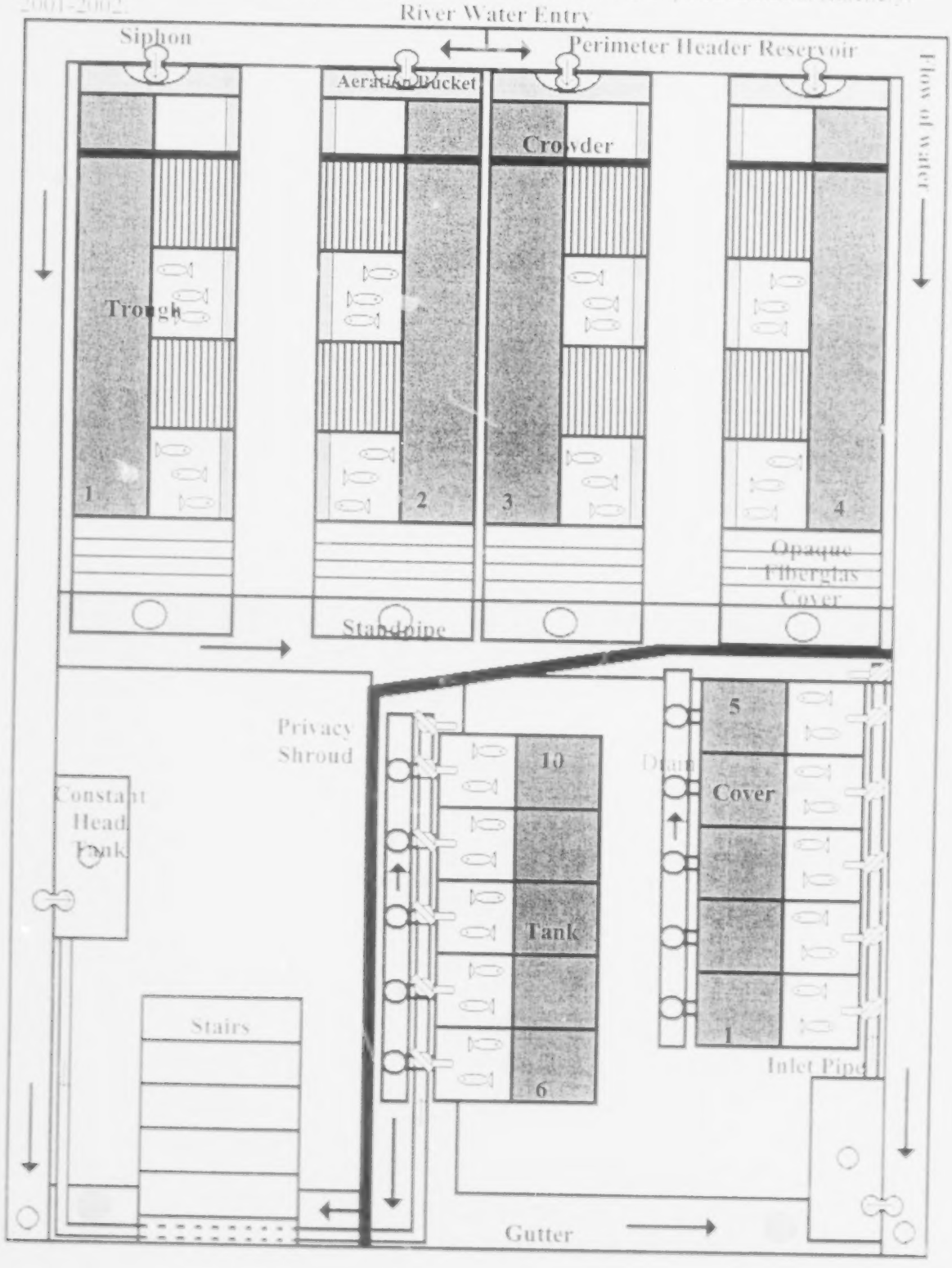


Figure 2. Schematic diagram of the cover response trial apparatus used at the Capilano Salmon Hatchery from January to May 2002.

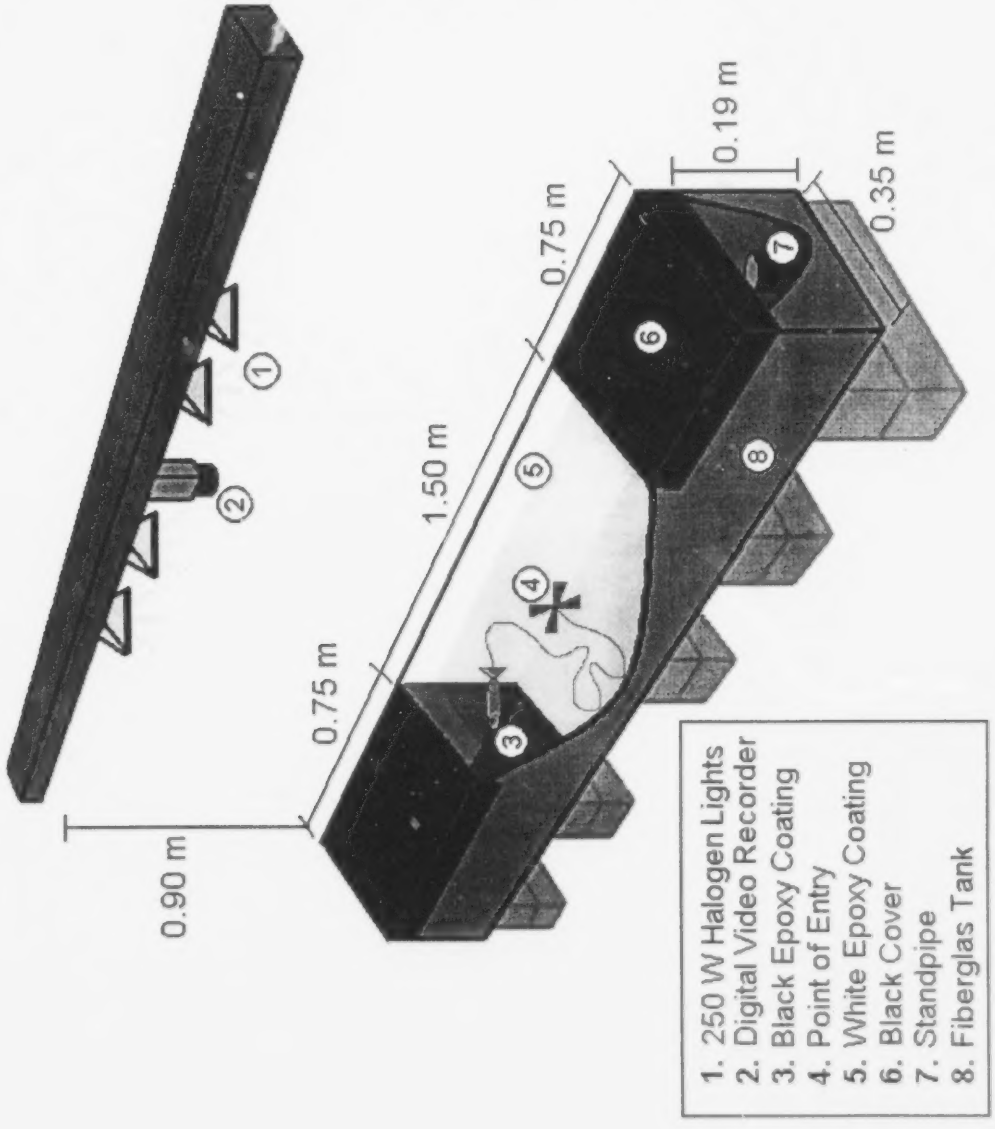


Figure 3. Daily determinations of turbidity (NTU) and temperature (° C) in experimental troughs between November 21, 2001 and May 30, 2002 at the Capilano Salmon Hatchery.

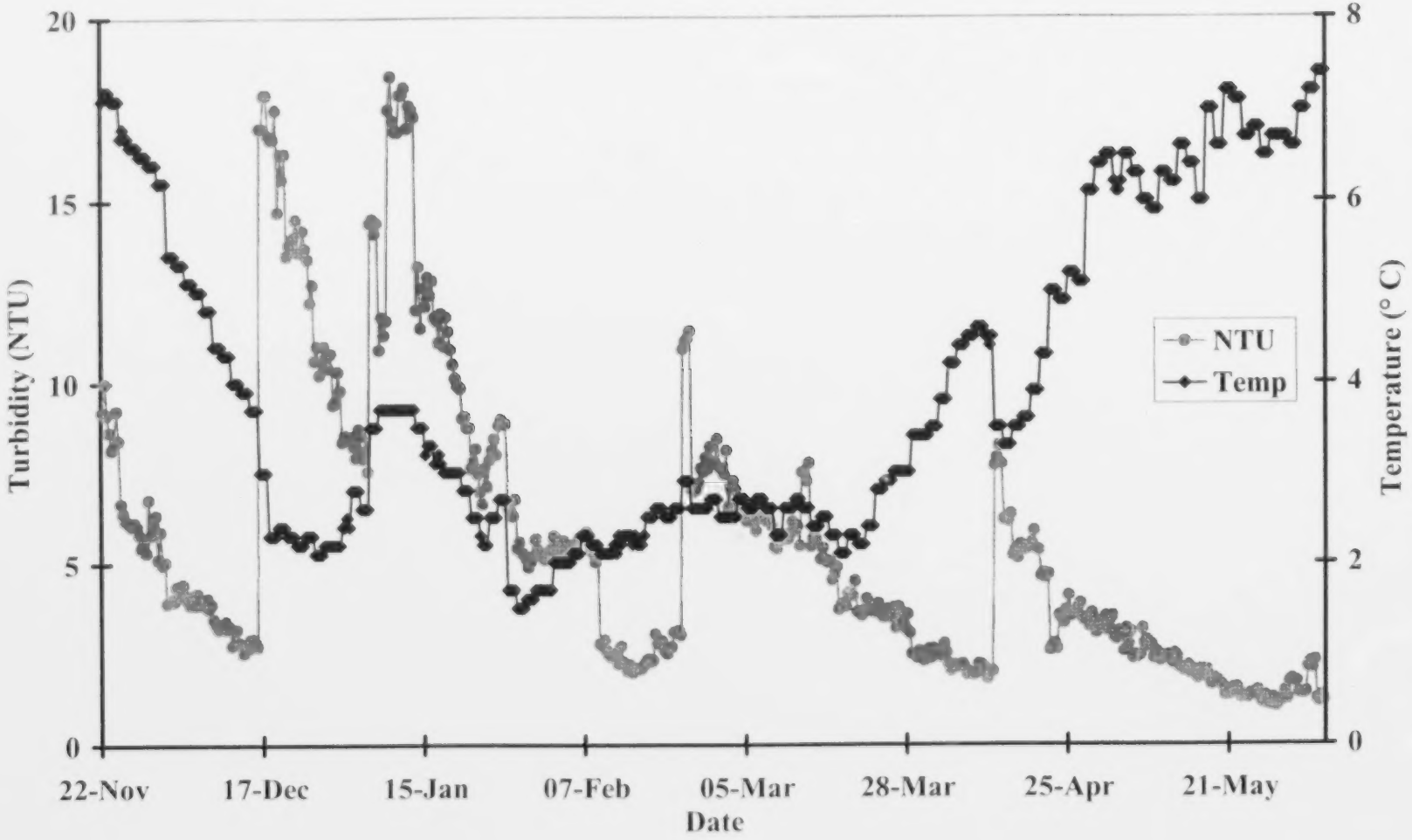


Figure 4. Daily determinations of turbidity (NTU) and temperature (° C) in experimental tanks between November 21, 2001 and May 30, 2002 at the Capilano Salmon Hatchery.

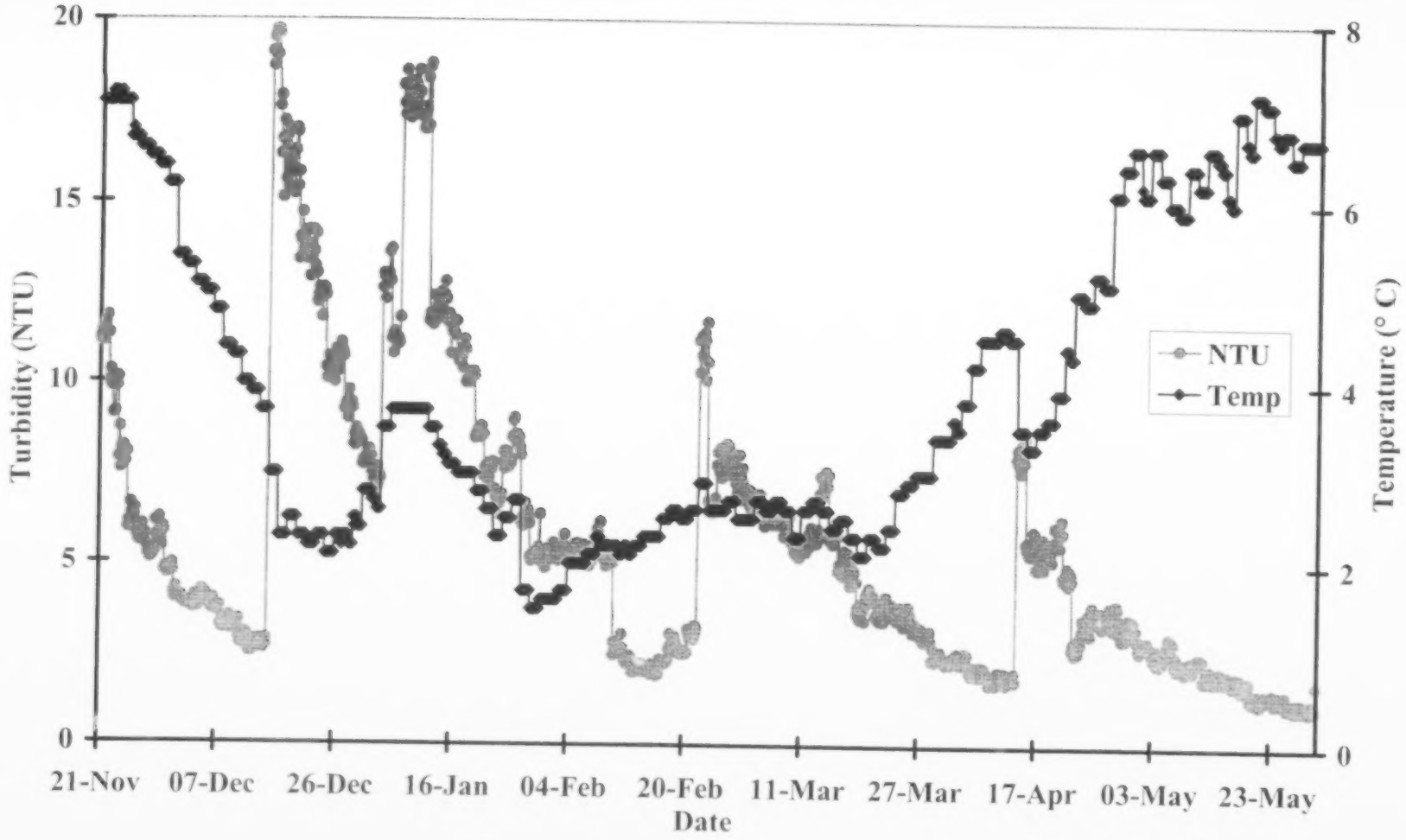


Figure 5. Turbidity (NTU) determined hourly in the water supply line to the experimental troughs and tanks between November, 2001 and June, 2002 at the Capilano Salmon Hatchery.

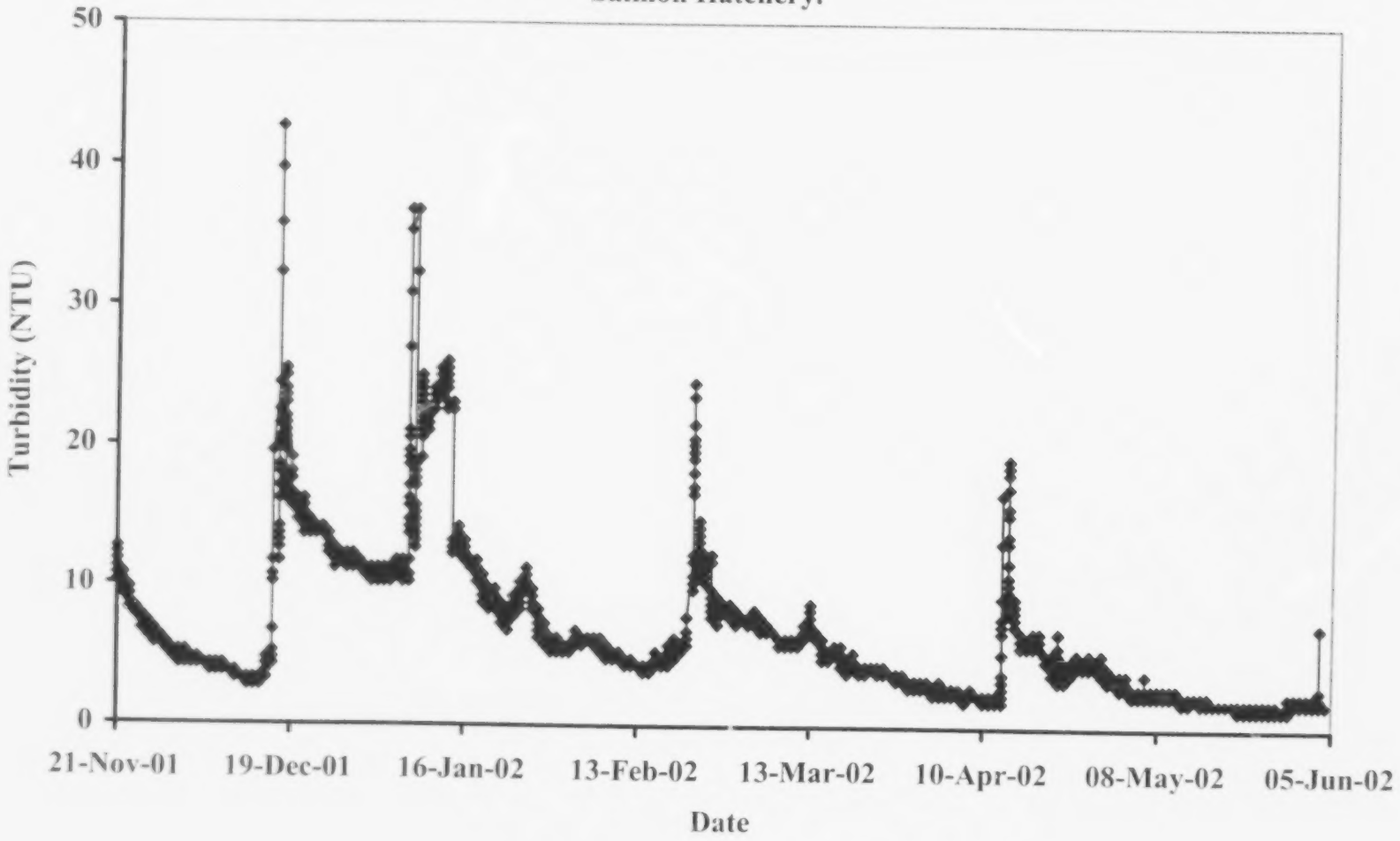
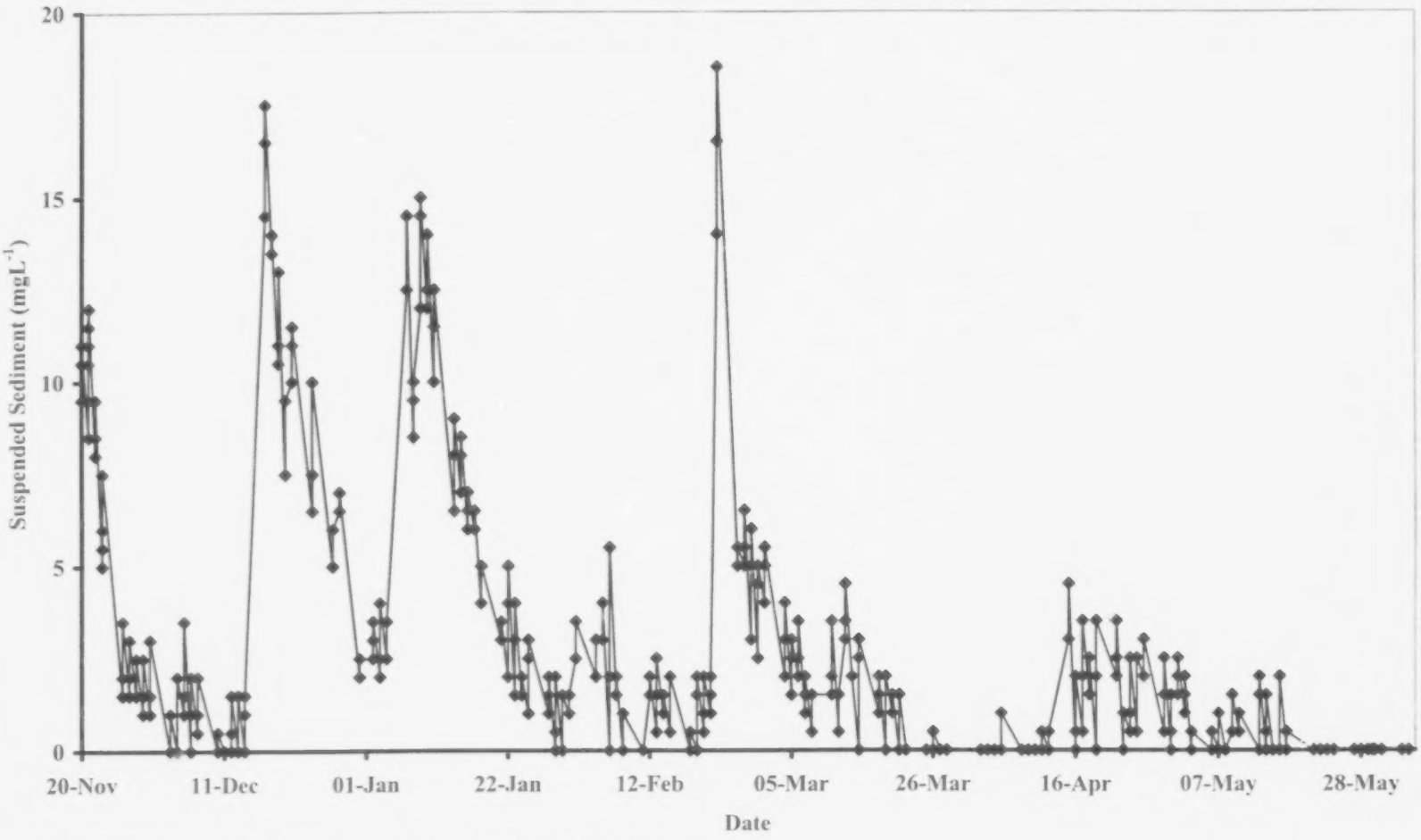


Figure 6. Determinations of suspended sediment in water samples from experimental troughs and tanks between November 20, 2001 to June 4, 2002 at the Capilano Salmon Hatchery.



note: Negative suspended sediment values arbitrarily set to zero.

Figure 7. Relationship between turbidity (NTU) and suspended sediment of experimental waters (troughs and tanks) at the Capilano Salmon Hatchery, November, 2001 to June, 2002.

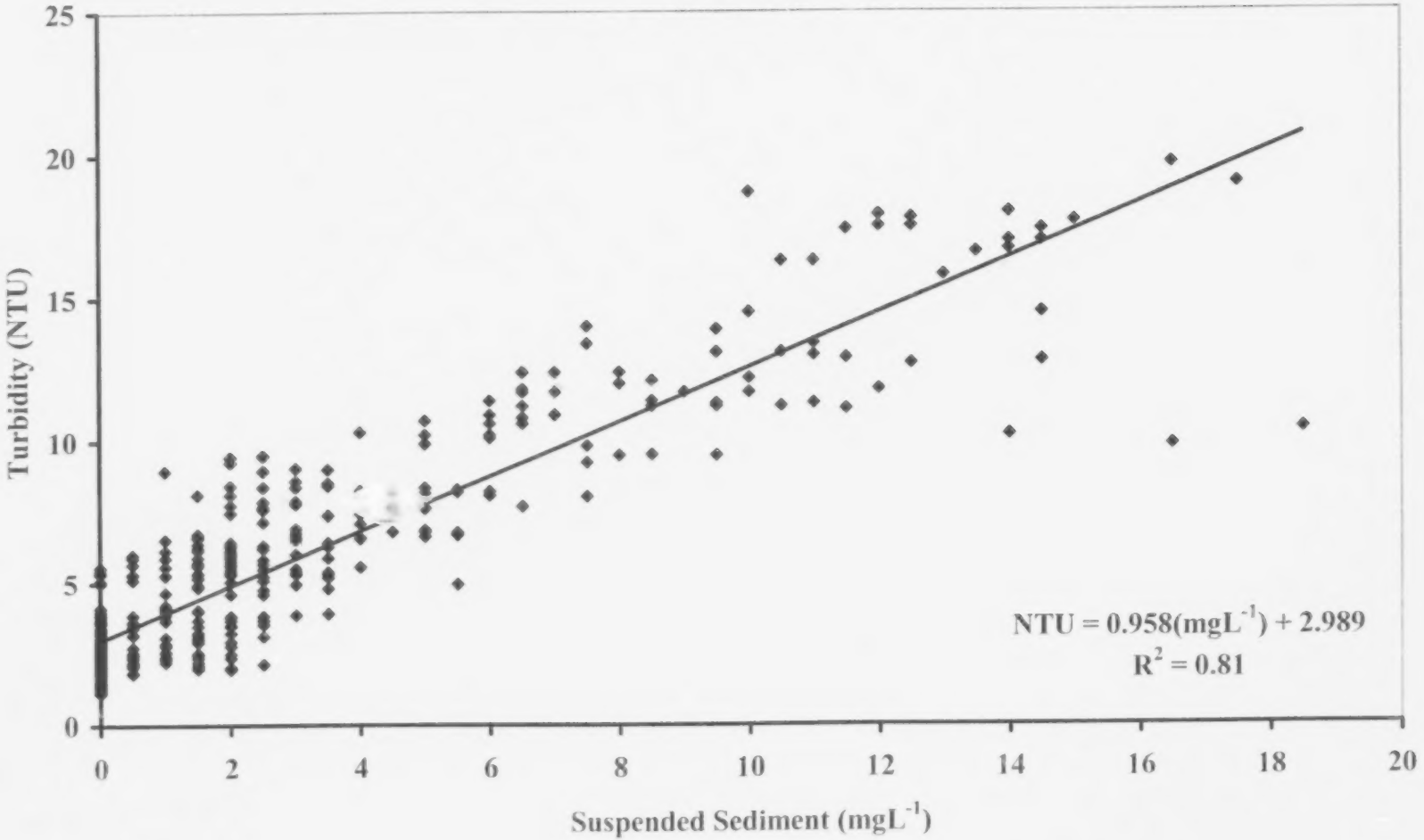
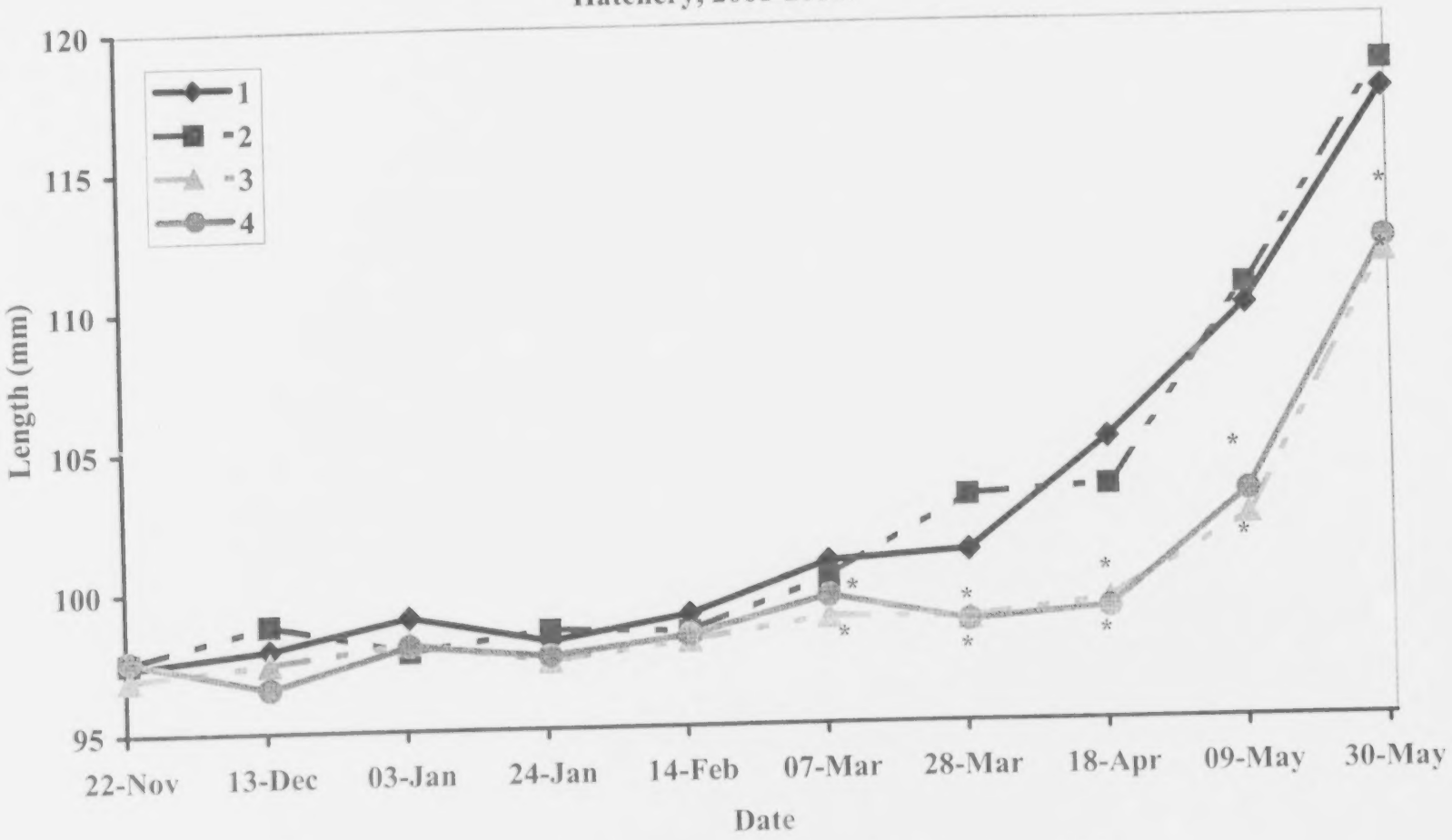
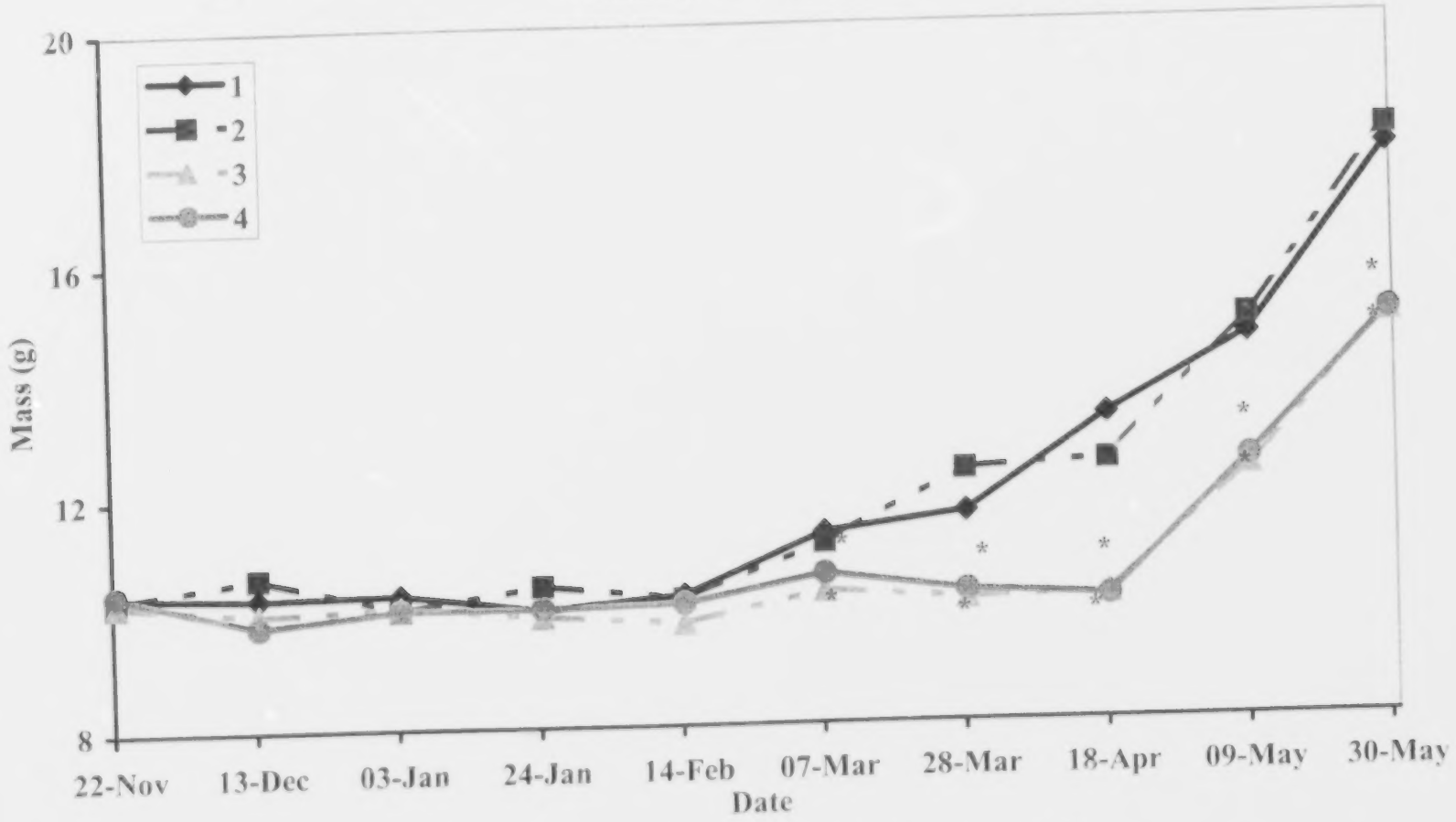


Figure 8. Mean length of juvenile coho salmon reared in experimental troughs, fed augmented (#1 and #2) and normal (#3 and #4) regimes at the Capilano Salmon Hatchery, 2001-2002.



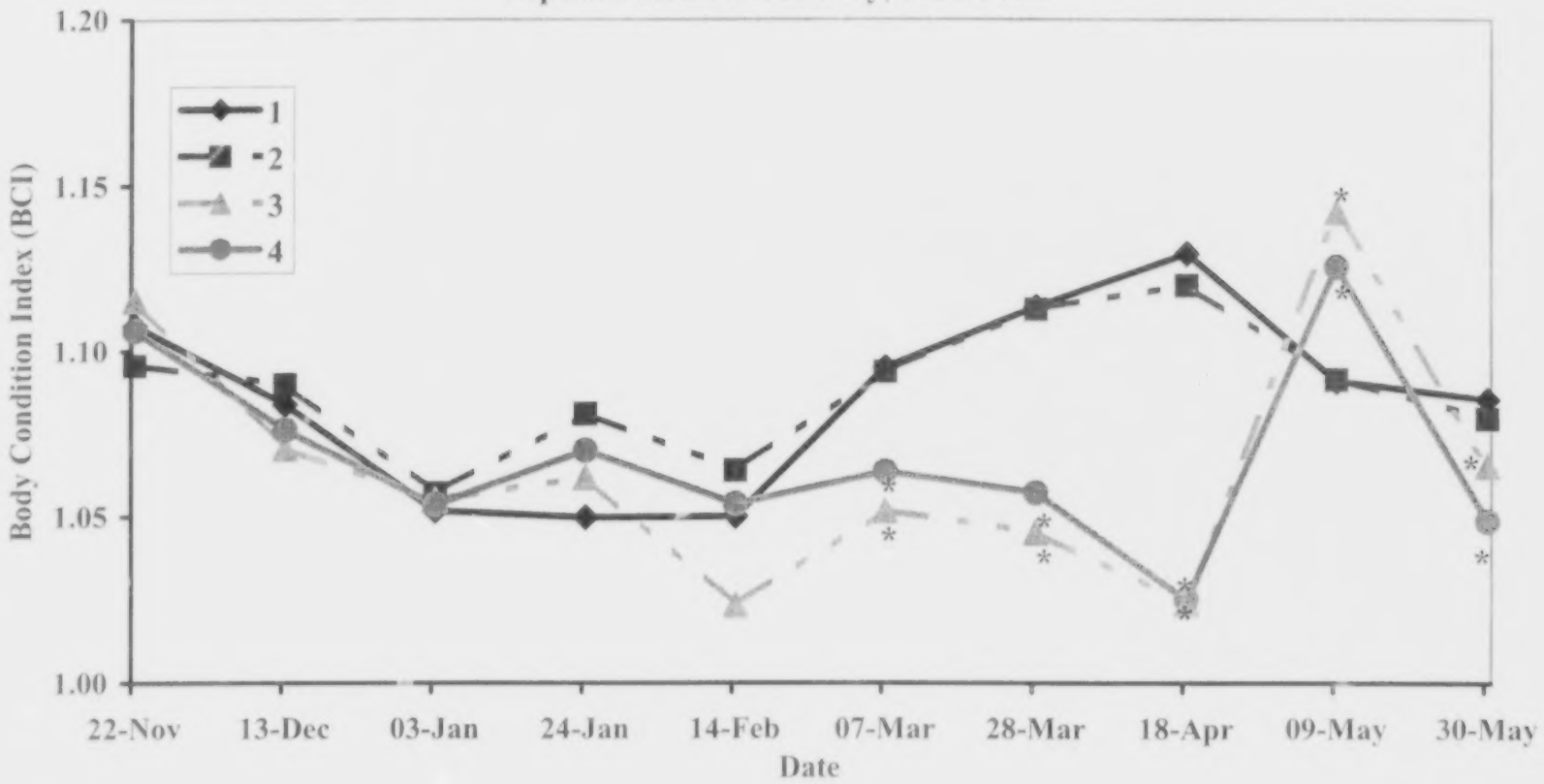
* Indicates significant difference between fish fed different feeding regimes in a Students t-test, $p<0.05$.

Figure 9. Mean mass of juvenile coho salmon reared in experimental troughs, fed augmented (#1 and #2) and normal (#3 and #4) regimes at the Capilano Salmon Hatchery, 2001-2002.



* Indicates significant difference between fish fed different feeding regimes in a Students t-test, $p<0.05$.

Figure 10. Mean Body Condition Index (BCI) of juvenile coho salmon reared in experimental troughs, fed augmented (#1 and #2) and normal (#3 and #4) regime at the Capilano Salmon Hatchery, 2001-2002.



* Indicates significant difference between fish fed different feeding regimes in a Students t-test, $p<0.05$.

Note: Feeding frequency in Troughs #3 and #4 increased from 1 x to 2 x a week April 15, 4 x a week April 22, 6 x a week April 29 and 7 x a week May 6. Feeding frequency in Troughs #1 and #2 increased from 5 x to 7x a week May 6.

Figure 11. Percentage change in mass of juvenile coho salmon reared in experimental troughs, fed augmented (#1 and #2) and normal (#3 and #4) regimes relative to initial determinations at the Capilano Salmon Hatchery, 2001-2002.

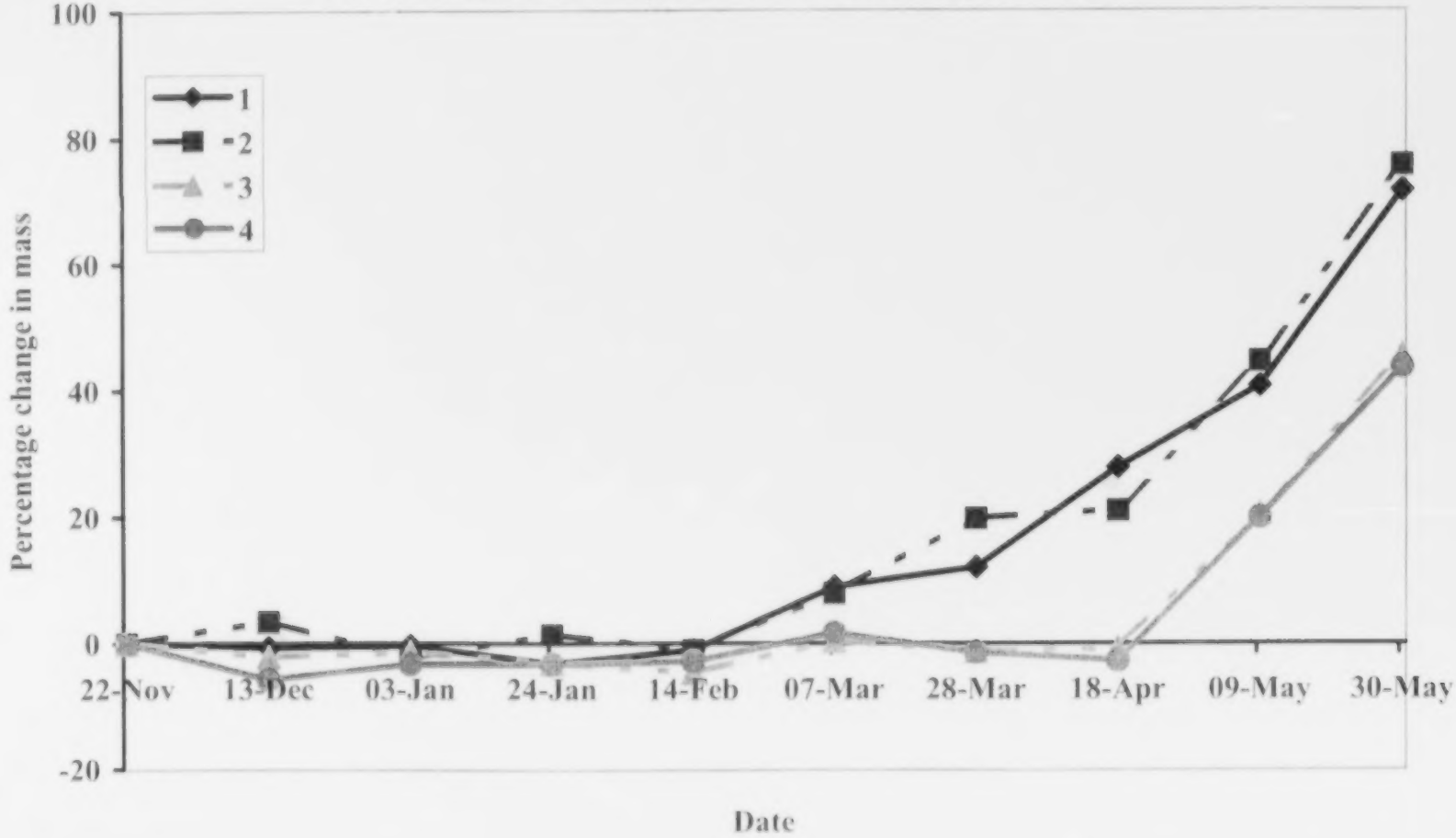


Figure 12. Mean length (mm) of juvenile coho salmon held in experimental tanks (n=20 per tank) from November 21, 2001 to May 29, 2002 at the Capilano Salmon Hatchery; all fish in tanks received the same feeding regime.

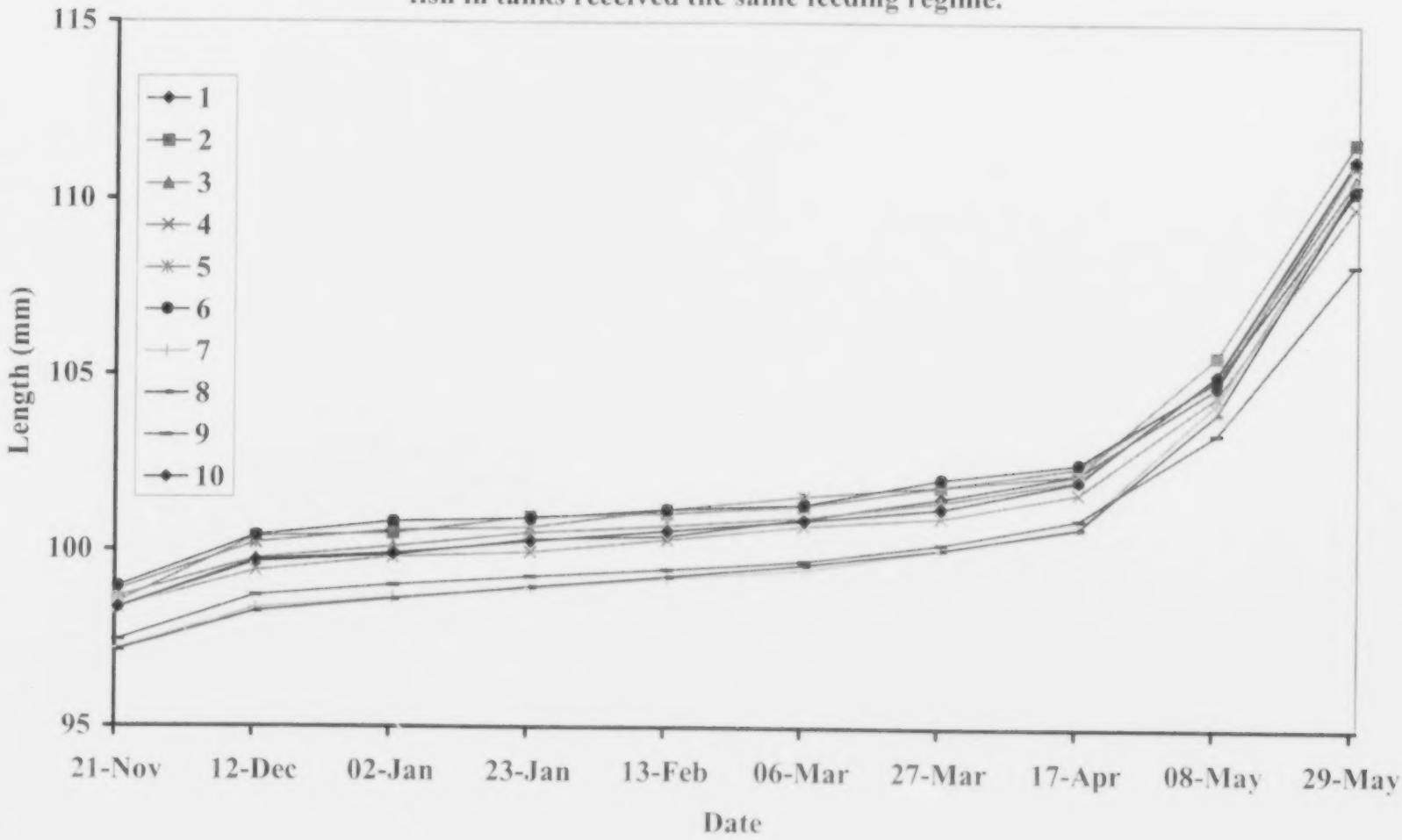


Figure 13. Mean mass (g) of juvenile salmon held in experimental tanks (n=20 per tank) from November 21, 2001 to May 29, 2002 at the Capilano Salmon Hatchery; all fish in tanks received the same feeding regime.

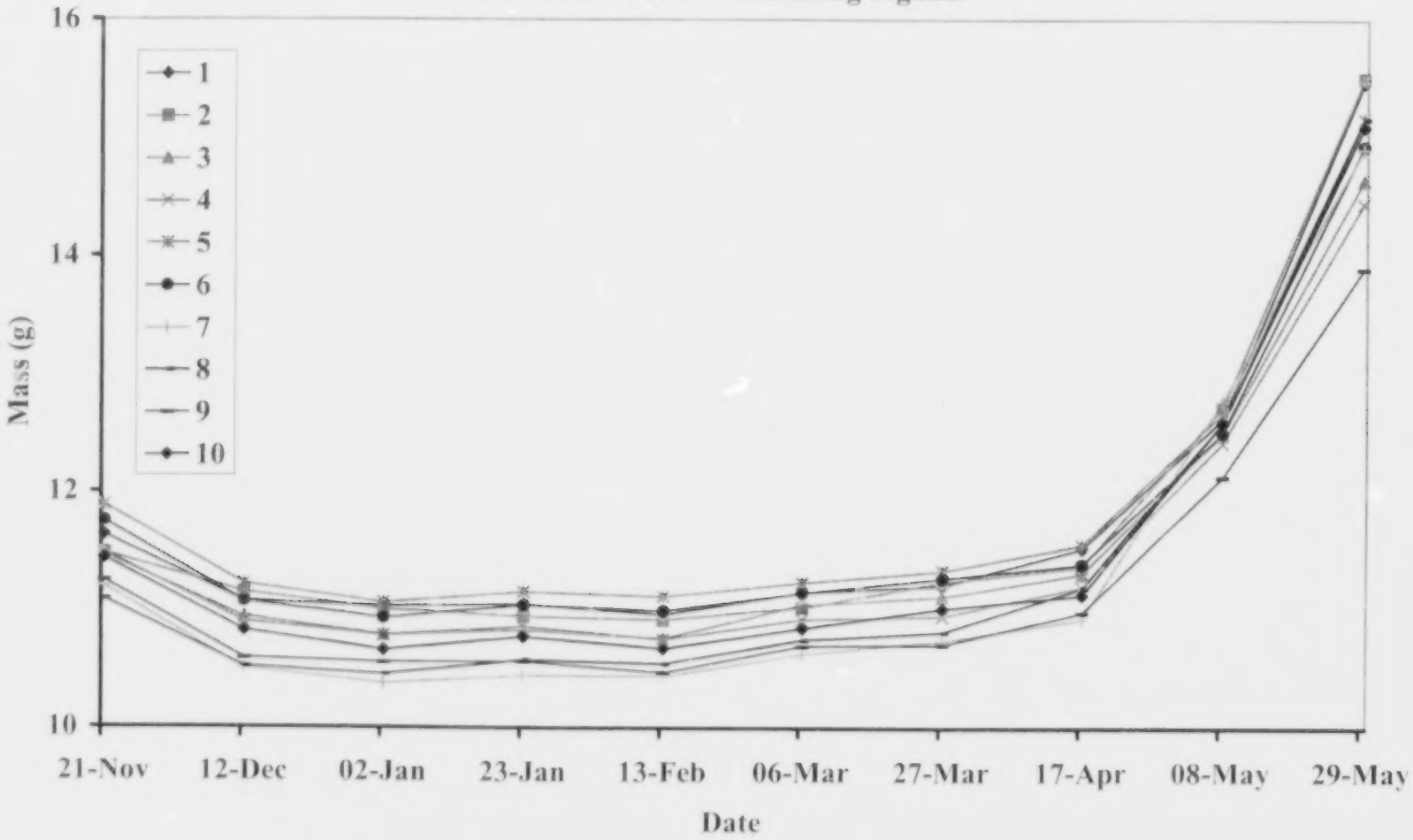


Figure 14. Mean Body Condition Index of juvenile salmon held in experimental tanks (n=20 per tank) from November 21, 2001 to May 29, 2002 at the Capilano Salmon Hatchery; all fish in tanks received the same feeding regime.

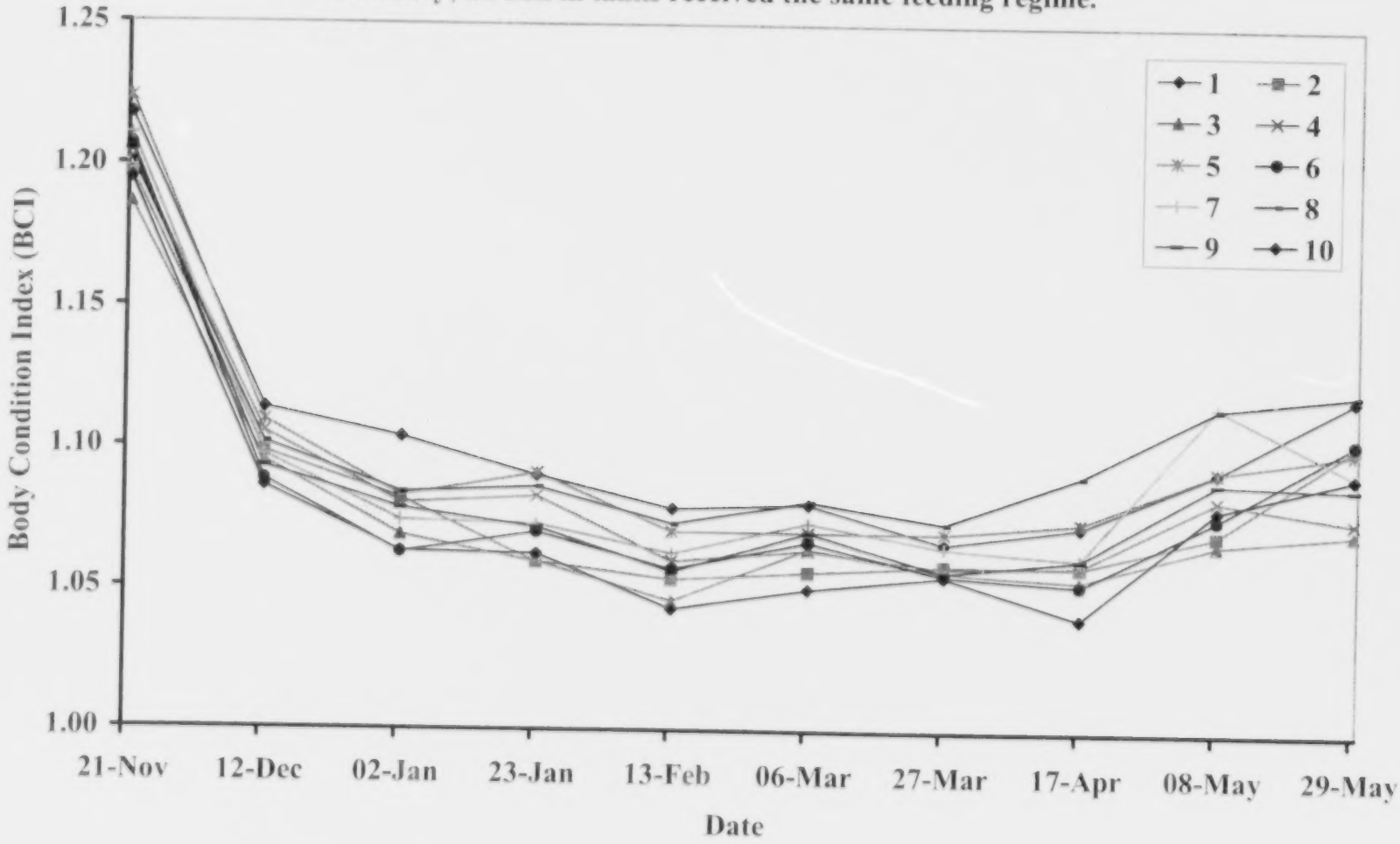
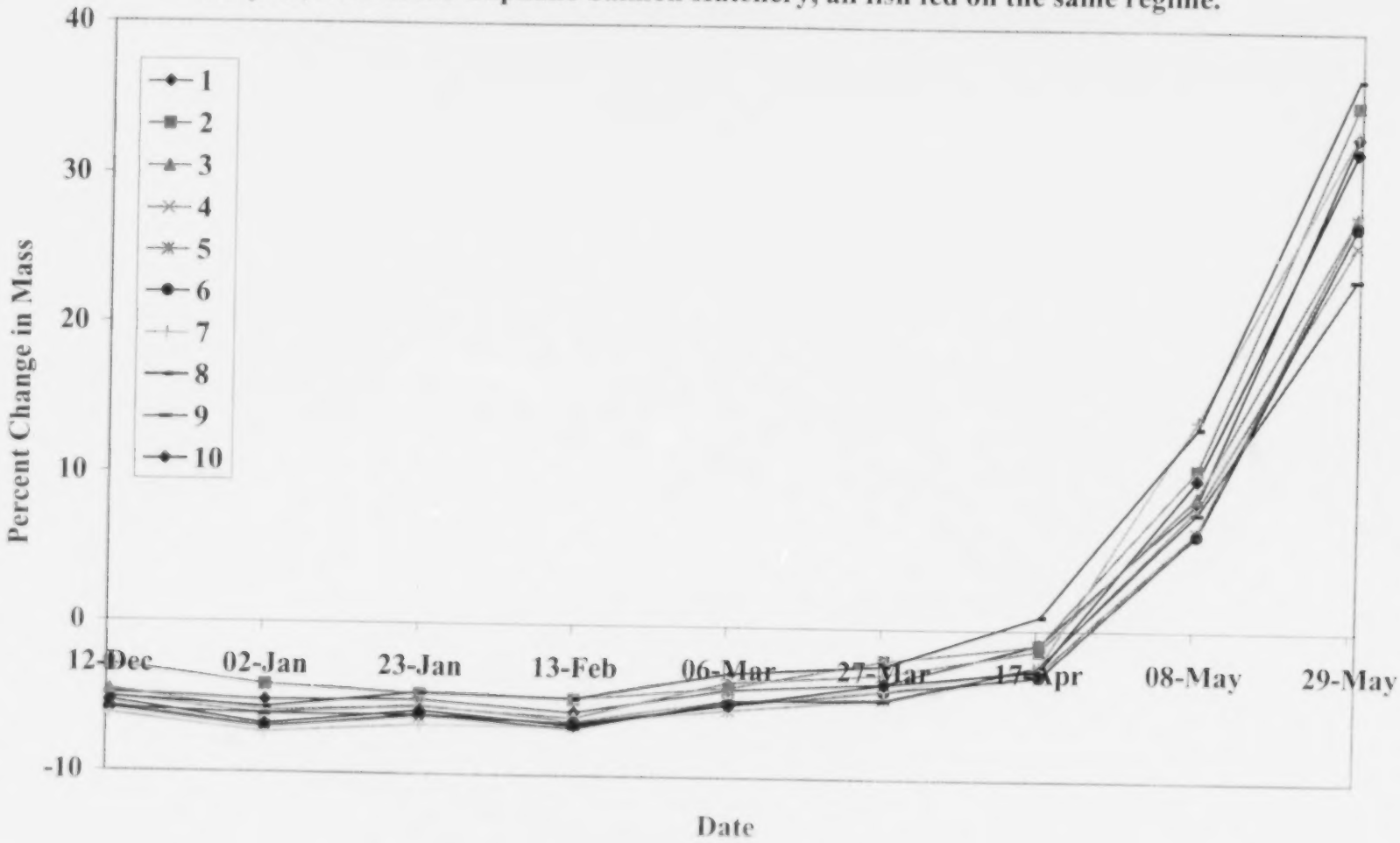


Figure 15. Percentage change in mean mass of juvenile coho salmon (n=20 per tank) relative to initial determinations held in experimental tanks from November 21, 2001 to May 29, 2002 at the Capilano Salmon Hatchery, all fish fed on the same regime.



APPENDIX I – 1999 HISTORICAL DATA

SUMMARY OF DATA AND FINDINGS

The data contained herein is unpublished data collected by the staff at the Capilano Salmon Hatchery (personal communication: Reid Schrul, Operations Manager, Capilano Salmon Hatchery, North Vancouver, BC).

From February 8, 1999 to April 12, 1999 turbidity (NTU) and total suspended sediment (SS, $mg \cdot L^{-1}$) were monitored both in water entering the Capilano Salmon Hatchery (Department of Fisheries and Oceans, North Vancouver, BC, Canada) and in the Capilano River itself (Table A1-1, Figure A1-1). During this period both turbidity and suspended sediment fluctuated, with mean (±SD) of 11.8 (±2.6) NTU and 11.5(±3.0) $mg \cdot L^{-1}$ in the Hatchery water and mean (±SD) of 16.0 (±3.0) NTU and 17.6 (±3.0) $mg \cdot L^{-1}$ in the River. There were two peaks in suspended sediment in both the hatchery and river water, these occurred on February 8-9, 1999 and February 25, 1999. The determinations of suspended sediment and turbidity on these dates in the hatchery waters were 21 $mg \cdot L^{-1}$ and 18.2 NTU on February 8, 1999 and 26 $mg \cdot L^{-1}$ and 23.9 NTU on February 25, 1999. In the river measurements of 47 $mg \cdot L^{-1}$ and 37.7 NTU on February 9, 1999 and 37 $mg \cdot L^{-1}$ 33.4 NTU on February 25, 1999 were determined.

Suspended sediment in the Capilano Salmon Hatchery waters fell below 5 $mg \cdot L^{-1}$ after March 29, 1999 and continued to decline until April 12, 1999 when the monitoring of turbidity and suspended sediment ceased.

Growth data from 1997 brood year coho salmon, that were being reared at the hatchery during the elevated suspended sediment event in late winter – early spring 1999 are presented in Table A1-3. This table shows the mean mass of the coho at time of ponding, at the beginning of elevated suspended sediment, during the event, at the end of the event, and at time of their release in comparison with predicted growth values (according to the *Capilano Salmon Hatchery Growth Model*; modified from Iwama and Tautz, 1981).

A summary of the 1997 brood year data are presented in Table A1-2, indicating that at the start of increased suspended sediment in hatchery waters the mean mass (g) of coho in 84% of the holding containers was below the value predicted by the growth model. Both during and at the end of the sediment event only 32% of containers of fish fell below predicted values while 68% were equal to or greater than that predicted. At the time of fish release 95% of the containers held fish that were less than predicted mass, one container of fish was equal to the predicted value; no containers of fish had a mean mass of fish greater than that which had been predicted. From this is would seem that during the period of elevated suspended sediment the coho were growing as expected while afterwards when the water became clear nearly all fish grew poorly.

Table A1-1. Total suspended sediment and turbidity measured from water samples collected in 1999 during the period of elevated

Date (1999)	River SS (mgL^{-1})	River Turbidity (NTU)	Hatchery SS (mgL^{-1})	Hatchery Turbidity (NTU)
08-Feb	19	17.6	21	18.2
09-Feb	47	37.7	19	16.5
10-Feb	42	35.6	13	14.5
11-Feb	23	22.8	13	14.2
13-Feb	14	13.2	13	13.8
14-Feb	17	12.6	14	12.8
15-Feb	10	10.8	12	11.2
22-Feb	9	10.1	9	11.2
25-Feb	37	33.4	26	23.9
26-Feb	35	30.8	12	18.2
02-Mar	8	12.6	8	9.2
08-Mar	13	8.2	10	7.2
15-Mar	9	7.5	9	8.4
23-Mar	4	6.0	6	9.1
29-Mar	6	5.6	4	4.6
08-Apr	3	3.0	3	2.6
12-Apr	3	3.9	3	4.4
Mean	17.6	16.0	11.5	11.8
Min	3	3	3	2.6
Max	47	37.7	26	23.9
SD	14.2	11.7	6.3	5.6

*Note: April 12 is the last sample point

TableA1-2. Percent of containers of fish according to actual mass in proportion to predicted mass, during sediment, after sediment, and at time of release.

Period	Percent of Containers with Mean Mass		
	Greater than Predicted	Equal to Predicted	Less than Predicted
Start of Sediment	11%	5%	84%
During Sediment	53%	16%	32%
End of Sediment	53%	16%	32%
Release	0%	5%	95%

Table A1-3. Growth data of all 1997 brood year coho salmon, from ponding in 1998 to release in 1999 including period of elevated suspended sediment from

		Actual	Predicted	% Mass Below
	Date	Mass (g)	Mass (g)	Predicted
Rearing	07-Jul-98	2.12		
	08-Feb-99	10.42	11.06	6%
	08-Mar-99	11.01	10.98	0%
	03-Apr-99	12.52	12.01	-4%
Pond 1	30-May-99	16.36	18.81	13%
Rearing	07-Jul-98	2.26		
	08-Feb-99	10.49	10.93	4%
	08-Mar-99	11.04	11.09	0%
	03-Apr-99	12.68	12.12	-5%
Pond 5	30-May-99	19.44	19.97	3%
Rearing	07-Jul-98	1.91		
	08-Feb-99	10.69	10.86	2%
	08-Mar-99	11.39	11.19	-2%
	03-Apr-99	11.41	12.13	6%
Pond 6	30-May-99	15.72	20.26	22%
Rearing	07-Jul-98	2.27		
	08-Feb-99	10.63	11.23	5%
	08-Mar-99	11.77	11.13	-6%
	03-Apr-99	11.78	12.37	5%
Pond 7	30-May-99	18.93	20.44	7%
Rearing	07-Jul-98	2.19		
	08-Feb-99	10.66	12.15	12%
	08-Mar-99	12.02	11.27	-7%
	03-Apr-99	12.03	12.63	5%
Pond 8	30-May-99	19.84	21.37	7%
Rearing	07-Jul-98	2.11		
	08-Feb-99	11.05	11.64	5%
	08-Mar-99	12.05	11.50	-5%
	03-Apr-99	12.11	12.66	4%
Pond 9	30-May-99	18.34	20.34	10%
Rearing	07-Jul-98	2.04		
	08-Feb-99	10.74	10.76	0%
	08-Mar-99	11.26	11.24	0%
	03-Apr-99	11.93	12.00	1%
Pond 10	30-May-99	16.08	20.04	20%
Basement	07-Jul-98	2.22		
	08-Feb-99	11.19	11.63	4%
Chamber	08-Mar-99	11.65	11.88	2%
	03-Apr-99	13.77	12.65	-9%
1A	30-May-99	13.76	16.27	15%

Table A1-3. Growth data of all 1997 brood year coho salmon, from ponding in 1998 to release in 1999 including period of elevated suspended sediment from

		Actual	Predicted	% Mass Below
	Date	Mass (g)	Mass (g)	Predicted
Basement	07-Jul-98	2.51		
	08-Feb-99	11.89	12.22	3%
Chamber	08-Mar-99	12.11	12.22	1%
	03-Apr-99	11.83	12.59	6%
1B	30-May-99	12.32	14.42	15%
Basement	07-Jul-98	2.07		
	08-Feb-99	11.94	11.66	-2%
Chamber	08-Mar-99	11.96	12.27	3%
	03-Apr-99	12.65	12.67	0%
4A	30-May-99	12.74	15.35	17%
Basement	07-Jul-98	1.99		
	08-Feb-99	11.07	11.43	3%
Chamber	08-Mar-99	11.47	11.78	3%
	03-Apr-99	12.65	12.53	-1%
4B	30-May-99	13.12	15.35	15%
Basement	07-Jul-98	1.90		
	08-Feb-99	11.86	12.14	2%
Chamber	08-Mar-99	12.79	12.47	-3%
	03-Apr-99	13.48	13.28	-2%
5A	30-May-99	15.42	15.45	0%
Basement	07-Jul-98	2.08		
	08-Feb-99	10.25	12.66	19%
Chamber	08-Mar-99	12.36	11.05	-12%
	03-Apr-99	12.06	13.00	7%
5B	30-May-99	12.02	13.90	14%
Basement	07-Jul-98	2.27		
	08-Feb-99	10.71	11.93	10%
Chamber	08-Mar-99	11.71	11.41	-3%
	03-Apr-99	12.71	12.55	-1%
6A	30-May-99	13.39	15.42	13%
Basement	07-Jul-98	2.13		
	08-Feb-99	11.15	11.24	1%
Chamber	08-Mar-99	11.43	11.66	2%
	03-Apr-99	12.87	12.30	-5%
6B	30-May-99	14.24	17.89	20%
Basement	07-Jul-98	1.90		
	08-Feb-99	10.41	11.15	7%
Chamber	08-Mar-99	11.88	11.07	-7%
	03-Apr-99	12.68	12.56	-1%
7A	30-May-99	14.43	17.74	19%

Table A1-3. Growth data of all 1997 brood year coho salmon, from ponding in 1998 to release in 1999 including period of elevated suspended sediment from

		Actual	Predicted	% Mass Below
	Date	Mass (g)	Mass (g)	Predicted
Rearing	07-Jul-98	2.12		
	08-Feb-99	10.42	11.06	6%
	08-Mar-99	11.01	10.98	0%
	03-Apr-99	12.52	12.01	-4%
Pond 1	30-May-99	16.36	18.81	13%
Rearing	07-Jul-98	2.26		
	08-Feb-99	10.49	10.93	4%
	08-Mar-99	11.04	11.09	0%
	03-Apr-99	12.68	12.12	-5%
Pond 5	30-May-99	19.44	19.97	3%
Rearing	07-Jul-98	1.91		
	08-Feb-99	10.69	10.86	2%
	08-Mar-99	11.39	11.19	-2%
	03-Apr-99	11.41	12.13	6%
Pond 6	30-May-99	15.72	20.26	22%
Rearing	07-Jul-98	2.27		
	08-Feb-99	10.63	11.23	5%
	08-Mar-99	11.77	11.13	-6%
	03-Apr-99	11.78	12.37	5%
Pond 7	30-May-99	18.93	20.44	7%
Rearing	07-Jul-98	2.19		
	08-Feb-99	10.66	12.15	12%
	08-Mar-99	12.02	11.27	-7%
	03-Apr-99	12.03	12.63	5%
Pond 8	30-May-99	19.84	21.37	7%
Rearing	07-Jul-98	2.11		
	08-Feb-99	11.05	11.64	5%
	08-Mar-99	12.05	11.50	-5%
	03-Apr-99	12.11	12.66	4%
Pond 9	30-May-99	18.34	20.34	10%
Rearing	07-Jul-98	2.04		
	08-Feb-99	10.74	10.76	0%
	08-Mar-99	11.26	11.24	0%
	03-Apr-99	11.93	12.00	1%
Pond 10	30-May-99	16.08	20.04	20%
Basement	07-Jul-98	2.22		
	08-Feb-99	11.19	11.63	4%
Chamber	08-Mar-99	11.65	11.88	2%
	03-Apr-99	13.77	12.65	-9%
1A	30-May-99	13.76	16.27	15%

Table A1-3. Growth data of all 1997 brood year coho salmon, from ponding in 1998 to release in 1999 including period of elevated suspended sediment from

	Date	Actual Mass (g)	Predicted Mass (g)	% Mass Below Predicted
Basement	07-Jul-98	2.51		
	08-Feb-99	11.89	12.22	3%
Chamber	08-Mar-99	12.11	12.22	1%
	03-Apr-99	11.83	12.59	6%
1B	30-May-99	12.22	14.42	15%
Basement	07-Jul-98	2.07		
	08-Feb-99	11.94	11.66	-2%
Chamber	08-Mar-99	11.96	12.27	3%
	03-Apr-99	12.65	12.67	0%
4A	30-May-99	12.74	15.35	17%
Basement	07-Jul-98	1.99		
	08-Feb-99	11.07	11.43	3%
Chamber	08-Mar-99	11.47	11.78	3%
	03-Apr-99	12.65	12.53	-1%
4B	30-May-99	13.12	15.35	15%
Basement	07-Jul-98	1.90		
	08-Feb-99	11.86	12.14	2%
Chamber	08-Mar-99	12.79	12.47	-3%
	03-Apr-99	13.48	13.28	-2%
5A	30-May-99	15.42	15.45	0%
Basement	07-Jul-98	2.08		
	08-Feb-99	10.25	12.66	19%
Chamber	08-Mar-99	12.36	11.05	-12%
	03-Apr-99	12.06	13.00	7%
5B	30-May-99	12.02	13.90	14%
Basement	07-Jul-98	2.27		
	08-Feb-99	10.71	11.93	10%
Chamber	08-Mar-99	11.71	11.41	-3%
	03-Apr-99	12.71	12.55	-1%
6A	30-May-99	13.39	15.42	13%
Basement	07-Jul-98	2.13		
	08-Feb-99	11.15	11.24	1%
Chamber	08-Mar-99	11.43	11.66	2%
	03-Apr-99	12.87	12.30	-5%
6B	30-May-99	14.24	17.89	20%
Basement	07-Jul-98	1.90		
	08-Feb-99	10.41	11.15	7%
Chamber	08-Mar-99	11.88	11.07	-7%
	03-Apr-99	12.68	12.56	-1%
7A	30-May-99	14.43	17.74	19%

Table A1-3. Growth data of all 1997 brood year coho salmon, from ponding in 1998 to release in 1999 including period of elevated suspended sediment from

		Actual	Predicted	% Mass Below
	Date	Mass (g)	Mass (g)	Predicted
Basement	07-Jul-98	1.93		
	08-Feb-99	10.79	11.53	6%
Chamber	08-Mar-99	11.86	11.35	-4%
	03-Apr-99	13.09	12.54	-4%
7B	30-May-99	14.06	18.25	23%
Basement	07-Jul-98	2.21		
	08-Feb-99	10.32	11.51	10%
Chamber	08-Mar-99	11.54	10.97	-5%
	03-Apr-99	12.36	12.47	1%
7C	30-May-99	14.13	17.58	20%
Basement	07-Jul-98	2.12		
	08-Feb-99	11.35	11.26	-1%
Chamber	08-Mar-99	10.88	11.67	7%
	03-Apr-99	12.36	11.98	-3%
7D	30-May-99	13.24	18.70	29%

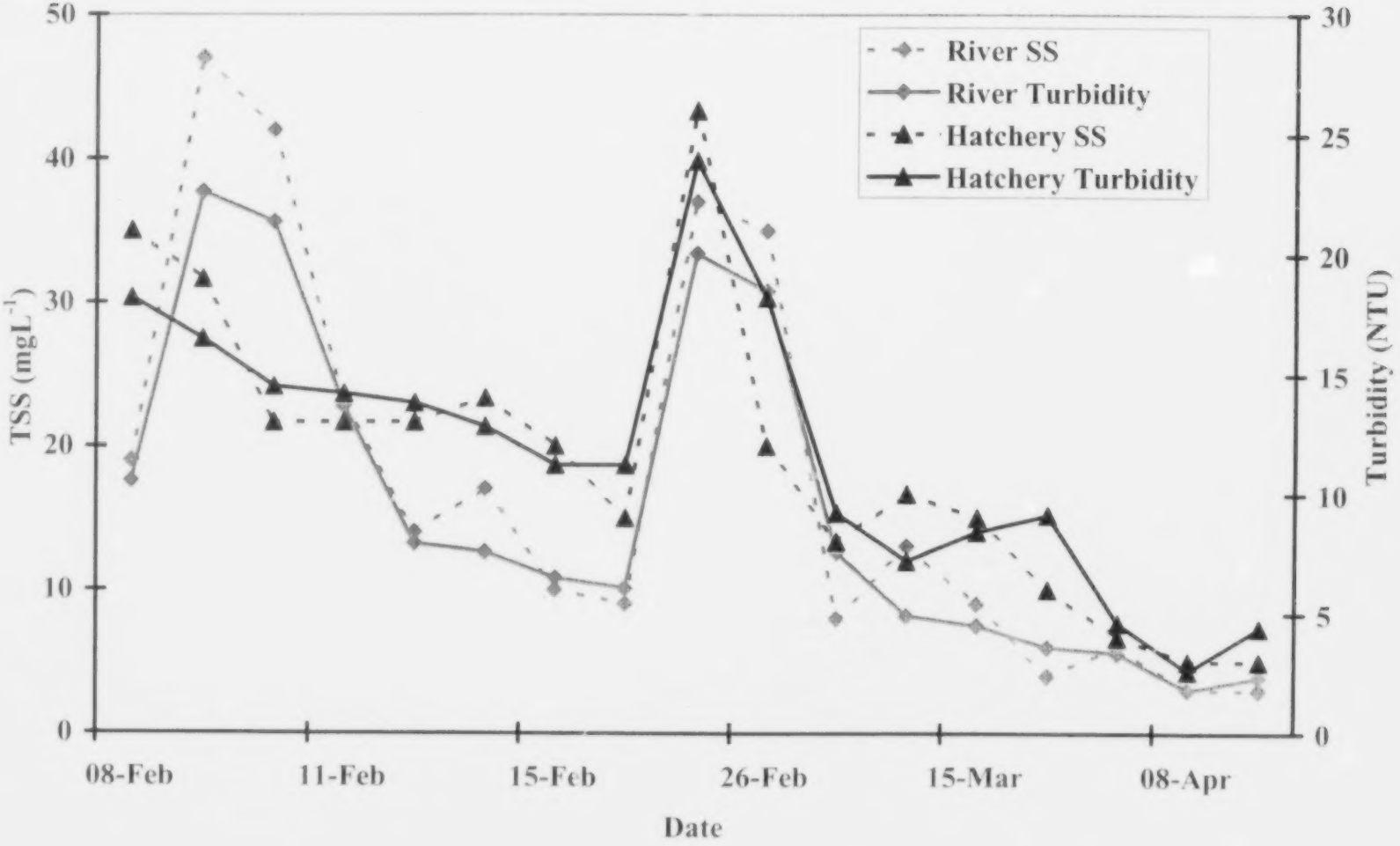
Note: Grey area indicates period of elevated sediment, July 7, 1998 - Coho ponded; May 30, 1999 - Coho released.

Table A1-3. Growth data of all 1997 brood year coho salmon, from ponding in 1998 to release in 1999 including period of elevated suspended sediment from

		Actual	Predicted	% Mass Below
	Date	Mass (g)	Mass (g)	Predicted
Basement	07-Jul-98	1.93		
	08-Feb-99	10.79	11.53	6%
Chamber	08-Mar-99	11.86	11.35	-4%
	03-Apr-99	13.09	12.54	-4%
7B	30-May-99	14.06	18.25	23%
Basement	07-Jul-98	2.21		
	08-Feb-99	10.32	11.51	10%
Chamber	08-Mar-99	11.54	10.97	-5%
	03-Apr-99	12.36	12.47	1%
7C	30-May-99	14.13	17.58	20%
Basement	07-Jul-98	2.12		
	08-Feb-99	11.35	11.26	-1%
Chamber	08-Mar-99	10.88	11.67	7%
	03-Apr-99	12.36	11.98	-3%
7D	30-May-99	13.24	18.70	29%

Note: Grey area indicates period of elevated sediment, July 7, 1998 - Coho ponded. May 30, 1999 - Coho released.

Figure A1-1. Turbidity and total suspended sediment of water samples collected in 1999 in the Capilano River and Capilano Hatchery during drawdown of the Cleveland Dam.



APPENDIX II - EXPERIMENTAL CONSIDERATIONS AND DESIGN

The following comments document the events and activities that occurred in relation to the design of the experiments and the practical issues of providing sediment-free water.

The initial concept for these experiments, which would assess the effects of anticipated elevated concentrations of suspended sediment, on fish held in the Capilano Salmon Hatchery, used one water supply; that of the Capilano Reservoir impounded by the Cleveland Dam. It was expected that the drawdown of the reservoir, to enable maintenance work on the dam, may indirectly result in elevated levels of sediment entering the reservoir waters, and hence the Capilano Hatchery. Thus, by filtering sediment from the water entering the hatchery, control water could be obtained. It was expected that determinations of the responses of fish exposed to the waters entering the hatchery would be compared with the same responses of fish exposed to control waters. This standard experimental concept of using control vs. treatment waters was originally accepted as a logical and feasible approach for the studies. A fundamental consideration was the successful removal of sediment from the incoming water and sufficient water flow rate and control.

Accordingly, discussions with those that supply and use filters revealed that it was possible to remove significant amounts of very fine sediment using standard filtration devices. Such an approach was identified by Klohn-Crippen Consultant Ltd. (2000) for the supply of water to the hatchery. In this report it is stated that about 60% of particles in Capilano Reservoir waters were <5 µm diameter in 1999. "During storm events, the particle size distribution of 11% less than 2 microns, 75% between 2 and 15 microns and, and 14% greater than 15 microns is expected to shift towards the larger particle sizes" (Klohn-Crippen Consultants Ltd., 1999; cited by Klohn-Crippen Consultants Ltd., 2000). Based on the advice of industry experts, sand filters were chosen as the best method for filtration, with the expectation of removal of 95% of particles down to 2-5 µm in size (and as low as 1 µm). Accordingly, it was expected that sand filters would be sufficient to remove the majority of fine suspended particles in the water entering the hatchery thus reducing turbidity and that this would be the source of control water for use in the experiments.

On September 26-28, 2001 two wound Fiberglas high rate sand filters (Triton II TR 60, Pac-Fab Inc., Sanford, NC, USA) were installed in the water supply line to the experimental chamber in the basement gallery of the hatchery. Two water pumps (Magnetek Centurion, A.O. Smith Corp., Milwaukee, WI, USA) were coupled to the filters. One was used to pressurise the incoming water to the sand filters, while the other was used for back washing and filter cleaning. Vancouver Mechanical Contractors Co. Ltd. (Vancouver, BC, Canada) installed the filters, pumps and plumbing that included two supply lines to the study chamber. The filters were filled with a 30/50 sand over 20/40 sand (where 20 represents number of openings per inch and 40 represents number of fractional openings per inch; supplied by Ideal Pool and Patio Supply Ltd., North Vancouver, BC, Canada), and equipped with automatic backwash valves and timers. October 9, 2001 new information was received from Ideal Pool and Patio Supply Ltd. that 30/50 sand was only capable of removing 95% of particles as small as 6 µm (vs. the previous 2-5 µm understood).

To keep control and treatment water separate the perimeter head reservoir (Figure 1) which supplied water to the fish holding apparatus was divided in half at the point of water entry. On October 2 and 4, 2001 a Fiberglas divider was installed (North West Fibre Mechanics Ltd., North

Vancouver, BC, Canada). Between October 4 and 25, 2001 an automatic control system for the water supply was designed and installed (Honeywell Ltd., Burnaby, BC, Canada) to initiate and control the filter backwash. This was necessary to ensure that one filter was constantly operating and supplying control (filtered) water. During this same time period (October 18 and 19, 2001) electrical work was undertaken to install a new water proof sub-panel, relocate existing wiring, and install high voltage cable to the water pumps (E.T.S. Electric Ltd., North Vancouver, BC, Canada).

Both the filtered and unfiltered supply lines had a continuously monitoring turbidity meter (Micro 200BW Turbidimeter, HF Scientific Inc, Ft. Myers, FL USA; precision 0.01; accuracy ± 2%; range 0-100 NTU) and data logger (HOBO®, Onset Computer Corporation, Bourne, MA, USA; accuracy ± 1% of full scale, range 0-20.1 mA) placed just prior to their entry to the study chamber. By October 26 2001 the filtration apparatus was completed and ready for start-up and testing. Representatives from Honeywell Ltd., Vancouver Mechanical Contractors Co. Ltd. and Ideal Pool and Patio Supply Ltd. were present to oversee this step.

From October 26 to 29, 2001 the sand filters were operated and the data logged every 5 min. Analysis of variance (ANOVA) comparing the filtered and unfiltered turbidity data was not significant ($p=0.7672$). The mean values of turbidity for the control water were marginally higher than unfiltered treatment water, 13.72 and 13.69 NTU respectively (Table A2-1). The higher mean turbidity level for the control water was most probably associated with spikes in turbidity concurrent with filter back wash events.

These tests determined that the filters were ineffective for the removal of particles causing the turbidity in the water entering the hatchery at this time. To verify the particle size of material within the incoming waters 2 L samples of both filtered and unfiltered water were sent to Soilcon Laboratories (Richmond, BC, Canada). Their analyses determined that approximately 65% of the sediment comprised particles ≥ 5 µm and approximately 95% was >2.5 µm (Table 12).

To remedy the filtration problem Les Hall Filter Service Ltd. (North Vancouver, BC, Canada) was contacted (L. Hall personal communication, November 1, 2001) regarding additional filtration possibilities. On November 5, 2001 a single 5 µm string wound polypropylene, 3" diameter x 10" long cartridge filter and assembly (XTL1M9-4A, Parker Hannifin Corp., USA) was installed (Honeywell Ltd, Burnaby, BC, Canada) between the sand filters and the turbidity meter. This was done to test the efficacy of the additional filters in achieving adequate control water (a total of 20 filtration cartridges and a 1.9 m assembly would be necessary to meet the flow requirements of the designed experiments; 80 $L \cdot min^{-1}$ of control water). Turbidity was logged over 16-h at 5 min intervals. ANOVA applied to the data for the control and unfiltered water revealed that the turbidity of the two waters was significantly different ($p<0.0001$). Application of a Student's t-test to the data similarly revealed a significant ($p<0.05$) and that the turbidity of the control water turbidity was significantly lower than that of the treatment water. Despite the statistical significance achieved with this filtration apparatus, mean turbidity in control water was 11.6 NTU, compared with 15.3 NTU in the unfiltered water (Table A2-1). We concluded that the modified filtration system only marginally reduced the turbidity (and hence suspended material) within the incoming waters to the hatchery, and that the residual turbidity in the filtered water (which indicated the presence of suspended material) was unacceptably high for the control water. Furthermore a minor reduction in

flow rate from the filters over the 16-h test was of concern considering that water flow was to be continuous and constant over the approximately 6 month experimental period.

November 6, 2001 the 30/50 sand in the filters was replaced with 50/100 sand (Ideal Pool and Patio Supply Ltd, North Vancouver, BC, Canada), which had a finer pore size (particle size captured unknown) and would capture more suspended sediment from the control water. This new replacement sand reduced water permeability in the filters thereby it also increased the operating pressure, which then exceeded a threshold resulting in a rapid and inappropriate cycling of back flushing in one sand filter rendering it useless, it was taken off line. Use of one sand filtration unit, before a 1 μm nominal graded density bonded polypropylene cartridge (EcoBond, Parker Hannifin Corp., USA), installed instead of the 5 μm string wound cartridge, was tested for their efficacy in removing suspended sediment. The turbidity in filtered control and unfiltered treatment water was determined on November 6 and 7, 2001. The results were comparable to those obtained during tests with a coarser filtration system i.e. 30/50 over 20/40 sand and 5 μm cartridge (Table A2-1). In addition, there was a significant reduction in water flow from 6 $L \cdot min^{-1}$ to < 1 $L \cdot min^{-1}$ over 22 h. Again, it was concluded that the filtration units were inadequate to provide the low turbidity/sediment free control water necessary for the experiments, and that flow control was unlikely.

The question was then raised as to the actual pore size of the 1 μm nominal cartridge. For this reason turbidity readings were taken before and after filtration of Capilano River water through the suspended sediment (SS) procedure (see 'Water Quality Monitoring' section) using a 1.2 μm pore size glass fibre filter and no rinse water. Turbidity dropped from 10.5 NTU before filtration to 1.58 NTU after filtration, an 85% reduction. These results indicated that a similar drop in turbidity should be observed if the cartridge was actually a 1 μm pore size cartridge filter.

On November 7, 2001 a 0.5 μm nominal pleated polypropylene cartridge (M710P010FUBY Maxima® Pleated Cartridge, Filtersoft®, Minneapolis, MN, USA) was installed after the sand filters (Honeywell Ltd. Burnaby, BC, Canada). This filter, had a specified 1.2 μm pore size (99.98% efficiency) and it produced a reduction of approximately ~87% in the turbidity of the incoming unfiltered water. A turbidity minimum of 1.7 NTU, (consistent with the suspended sediment results mentioned above, for a similar pore size) was produced which was considered appropriate for the control water in the experiments (Table A2-1). Unfortunately, this cartridge filter caused an immediate drop in flow rate after installation and required 20-30 psi to operate. The filter was tested at a low flow of 2 $L \cdot min^{-1}$ which rapidly decreased to 0.7 $L \cdot min^{-1}$ over 1.5 h and to 0.1 $L \cdot min^{-1}$ over 20 h. Filtration of an adequate supply of the filtered water would have required 20 cartridges in a 1.9 m housing, and the cartridges would have had to be replaced daily. Thus, despite the effective filtration of water using this combination of filters, it was not feasible to control the flow and thereby supply enough water to the experimental apparatus over time. Furthermore, the replacement of the filtration cartridges would have been problematic for practical and economic reasons.

It was concluded (November 13, 2001) that it was not feasible to provide a continuous and controlled supply of water that would be suitable for use as control water, despite the above-mentioned efforts to filter sediment from waters entering the hatchery. An alternative and compromise design was now employed that would rely upon a repeated measures base for the

determination of effects. For this approach all fish within the experiment would be supplied with the same source of unfiltered water, and that by sampling the fish at discrete sampling periods over the course of the study any cumulative and specific effects due to measured variables may be determined. This approach presupposes that there will be events during the course of the experiment that would invoke responses in the fish and that they would be manifest or integrated through the responses examined (e.g. nutritional state, growth). It was expected that the sampling of fish and determinations of their responses would be flexible and modified if the quality of water changed rapidly and became potentially stressful to them.

Table A2-1. Mean turbidity determined in the control and treatment water supply lines to the experimental chamber with each filter configuration in operation, October - November 2001 at the Capilano River Hatchery.

	Turbidity (NTU)				
Filter Apparatus	**Sand Filter**	**Sand Filter**	**Sand Filter**	**Sand Filter**	**Sand Filter**
		(30/50 Sand)		**(50/100 Sand)**	**(50/100 Sand) +**
		+ 5 µm		**+ 1 µm**	**0.5 µm**
Configuration	**(30/50 Sand)**	**Cartridge**	**(50/100 Sand)**	**Cartridge (Nominal)**	**Cartridge (1.2 µm absolute)**
Control (Filtered)	13.72	11.58	13.42	9.58	3.30
Treatment (Unfiltered)	13.69	15.26	13.83	13.59	12.75